July 1955

NUCLEONICS

A McGRAW-HILL PUBLICATION ★ SEVENTY-FIVE CENTS

Phenolic...
SWELLS

Unirradiated | 10^9 rad | 10^{10} rad

Polyester...
SHRINKS

Unirradiated | 10^7 rad | $5x10^8$ rad

Polyethylene...
HARDENS

Unirradiated | 10^9 rad | 10^{10} rad

Butyl Rubber...
SOFTENS

Unirradiated | 10^8 rad | $5x10^8$ rad

Radiation Stability of Plastics and Elastomers—p. 28

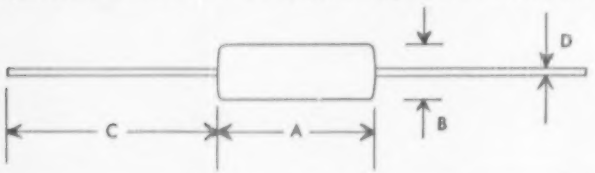
NOW

1/8, 1/4 and 1/2 watt *Molded* Precistors

IRC *molded* Deposited and Boron Carbon Precistors are now available in 1/8, 1/4 and 1/2 watt sizes. These 1% precision film type resistors combine the advantages of high stability, small size and low cost in either deposited carbon or boron carbon units. Ratings are based on full load at 70°C. ambient.

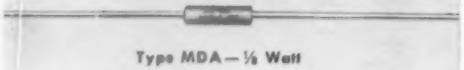
The *molded* plastic housing provides complete mechanical protection, minimizes the effect of moisture and improves load life characteristics.

Equivalent In Size To IRC's Popular Types BTS • BW½ • BTA



Precistor Types	IRC Size Equivalent	Dimension			
		A	B	C	D
MDA — MBA	BTS	13/32"	1/8"	1 1/2"	.025"
MDB — MBB	BW½	3/8"	1/4"	1 1/2"	.025"
MDC — MBC	BTA	13/32"	1/4"	1 1/2"	.032"

MOLDED DEPOSITED CARBON PRECISTORS

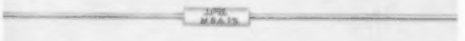


Type MDA — 1/8 Watt

Type MDB — 1/4 Watt

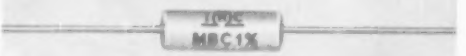
Type MDC — 1/2 Watt

MOLDED BORON CARBON PRECISTORS



Type MBA — 1/8 Watt

Type MBB — 1/4 Watt



Type MBC — 1/2 Watt

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NUCLEONICS

JULY • 1955

Vol. 13, No. 7

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NUCLEONICS (with which is consolidated "Atomic Power" and "Atomic Engineering") July, 1955, Vol. 13, No. 7. Published monthly by the McGraw-Hill Publishing Co., Inc., Executive, Editorial, Advertising and Subscription Offices: **McGraw-Hill Building, 330 West 42nd Street, N. Y. 36, N. Y.** Publication Office, 212 East York St., York, Pa. Entered as second class matter December 17, 1947, in the Post Office at York, Pa., under the act of March 3, 1879.

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FOR SUBSCRIPTIONS, write to Nucleonics-Subscription Service, 330 West 42nd Street, New York 36, N. Y. **Orders must indicate company and position.** Allow one month for change of address. Price per copy $.75. Subscription rates: United States and U. S. Possessions $8 for 1 year, $12 for 2 years, $16 for 3 years. Canada $10 for 1 year, $16 for 2 years, $20 for 3 years. Other Western Hemisphere countries and the Philippines $15 for 1 year, $25 for 2 years, $30 for 3 years. All other countries $20 for 1 year, $30 for 2 years, $40 for 3 years. Member of ABC. Member of ABP.

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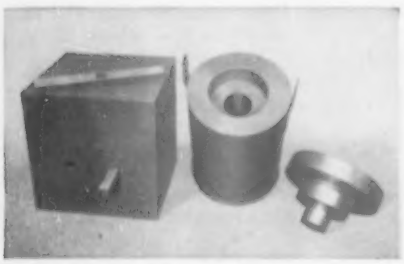
For high density in small volume... For maximum adaptability... Lead



Typical lead shielding items – lead safe (cube), lead cask and extruded curved-joint lead brick.

Lead shielding has greater density (11.35 at 20°C) than any material anywhere near its cost—a worthwhile advantage when *space* and *money* are limited.

Where circumstances necessitate re-working or re-shaping standard on-hand lead brick, slab, pipe or sheet, a melting point of 327.4°C and excellent ductility are advantageous.

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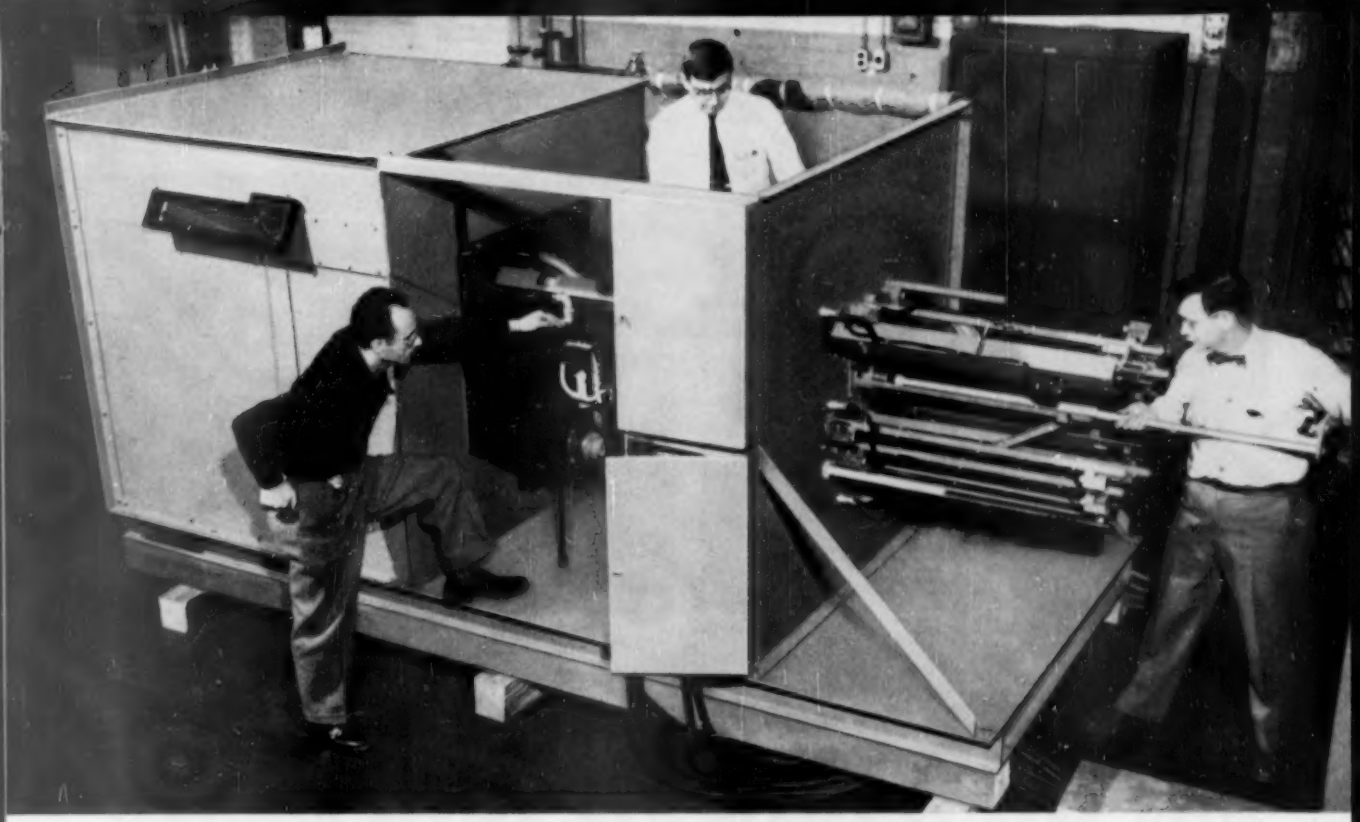

G-E Nuclear Test Reactor

New G-E 7-point program helps you plan and obtain nuclear research reactor

To help industrial, educational, and research organizations plan and obtain nuclear research reactors quickly, General Electric offers a new seven-point program.

7-point research reactor program

General Electric offers to:

1 **PREPARE REACTOR SPECIFICATIONS,** meeting your specific research requirements

2 **CO-ORDINATE BUILDING STUDY,** assuring proper housing of reactor

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5 **INSTALL REACTOR SYSTEM** at your location

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7 **PROVIDE REACTOR SERVICE** to maintain reactor system in proper working order

By providing a large quantity of neutrons at power levels from one watt to 5000 kw, General Electric research reactors can be used as neutron beam generators, for production of radioisotopes, irradiation studies, and nuclear engineering studies. The use of these research reactors will be governed by the Atomic Energy Act of 1954. G.E. will also design and manufacture components for nuclear reactor systems.

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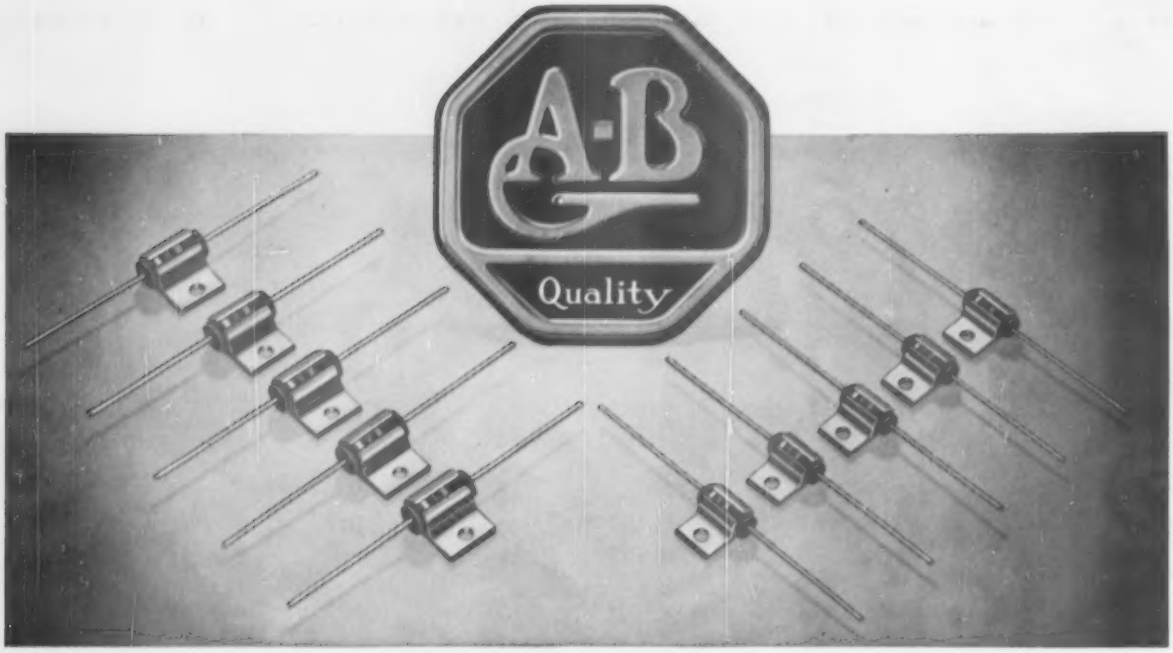


ALLEN-BRADLEY COPPER CLAD MOLDED RESISTORS

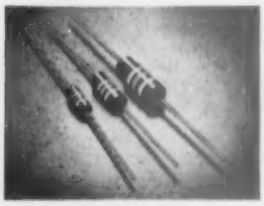
rated at 3 and 4 watts at 70C Ambient Temperature

A new and important addition to the Allen-Bradley line of radio, electronic, and television components are these Types GM and HM copper clad Bradleyunits, each fitted with a heavily tinned copper clamp. These new resistors are designed to be attached to a metal panel or chassis with rivets, bolts, or self-tapping screws. If attached to a metal panel four inches square and 0.050 in. thick at an ambient temperature of 70C, the maximum continuous wattage rating of the Type GM Bradleyunit is 3 watts; the Type HM Bradleyunit is 4 watts. At 40C ambient temperature, the ratings are 4 and 5 watts, respectively. However, if these copper clad Bradleyunits are suspended by their leads without being bolted to a metal panel, their respective ratings are 1 and 2 watts.

The copper clamp does not completely encircle the Bradleyunit, thus leaving a slot through which the color-code bands are plainly visible. Type GM Bradleyunits are available in all RETMA values from 2.7 to 22 megohms and Type HM Bradleyunits from 10 ohms to 22 megohms.

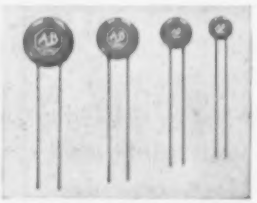
Allen-Bradley Co., 106 W. Greenfield Ave., Milwaukee 4, Wis. • In Canada—Allen-Bradley Canada Limited, Galt, Ont.

OTHER QUALITY COMPONENTS FOR RADIO, TV & ELECTRONIC APPLICATIONS



BRADLEYUNITS
1/2, 1, 2, 3 & 4 WATT

BRADLEYOMETERS
1/2 & 2 WATT



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HIGH EFFICIENCY

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RADIO, ELECTRONIC AND TELEVISION COMPONENTS

A Primer of Gas Turbine Engines

What is the man above holding?

He is holding a Solar "Mars" gas turbine engine. Its power output runs to 50 hp, but it weighs less than 100 lb and is smaller than a two-foot cube. It achieves this remarkable power-to-size ratio by running at a high speed: the shaft in this engine turns at 40,000 rpm!

Where are gas turbine engines being used?

Gas turbines today are finding an increasing variety of uses: in boats, where compactness is important; in airplanes, where light weight is essential; in remote pumping stations, where portability counts; in electric power plants, where reliability must be assured.

What advantages do small gas turbines offer?

Gas turbines are extremely light and compact; they permit smaller space envelopes and easy transportation, so important in such applications as portable fire pumps and airborne generator sets (photo above). Gas turbines are simple and rugged, with low maintenance cost. They need no cooling system and will operate on a variety of fuels. Low initial cost is anticipated, when gas turbines reach volume production.

What gas turbines are made by Solar?

Today in addition to the 50 hp Mars gas turbine, Solar is producing the 500 hp Jupiter gas turbine (photo above). Its weight installed is under 900 lb—less than one fourth that of a comparable diesel engine!

Mars engines have been adapted to many applications such as fire pumps, starter carts, and welding equipment, and they are in volume production for auxiliary generator sets used on the Douglas C-124C and Lockheed C-121C. Both constant speed Jupiter engines for generator sets and variable speed engines for ship propulsion have been built for the U.S. Navy.

Solar gas turbines are not yet generally available as all current production is going into military uses. Field testing of commercial applications is underway and production for civilian use is anticipated in the near future. Further information is available on request.

SOLAR AIRCRAFT COMPANY — SAN DIEGO, DES MOINES

DESIGNERS, DEVELOPERS AND MANUFACTURERS OF METAL ALLOY PRODUCTS

This is What Solar Offers You

When heat, corrosion or difficult specifications are problems, Solar can help you solve them. Solar specializes in the manufacture of precision products from alloys and special metals for severe service. Solar's experience since 1927 is unduplicated in this field.

SPECIAL PRODUCTS

Gas Turbines. *Solar "Mars" 50 hp engines for auxiliary generator sets, ground carts, portable fire pumps; Solar "Jupiter" 500 hp engines in variable and constant speed models.*

Bellows. *"Sola-Flex"® bellows and expansion joints in many designs from ½ in up to the world's largest, 28 ft in diameter.*

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CONTRACT PRODUCTION

Current orders include aircraft engine and airframe parts, pneumatic ducting, atomic energy components. Customers include the finest aircraft and industrial companies in the U.S. and Europe.

Plants. *In San Diego and Des Moines (photograph above). A total of 1,400,000 sq ft of floor space. Approximately 5,000 employees. Annual sales over $65,000,000.*

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INFORMATION

For more information regarding Solar Gas Turbines or any Solar product or service listed above, write Solar Aircraft Company Department B-31 San Diego 12, California

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Thompson Products, Inc. of Cleveland, Ohio has installed the illustrated high-vacuum furnace to aid in its investigation of new and improved materials for the automotive and aircraft industries. Currently rated at 200-pound melt capacity, Thompson's furnace is capable of 1000-pound production with minor modification, an important advantage should full-scale vacuum metal production be initiated.

Stokes is the leading supplier of production vacuum furnaces for industry. Any of the basic furnace designs, ranging from laboratory units to 1000-pound capacity and higher, can be modified to meet your particular requirements. If your interest lies in high-purity metals, write for your free copy of Stokes Catalog 790, "High-Vacuum Furnaces."

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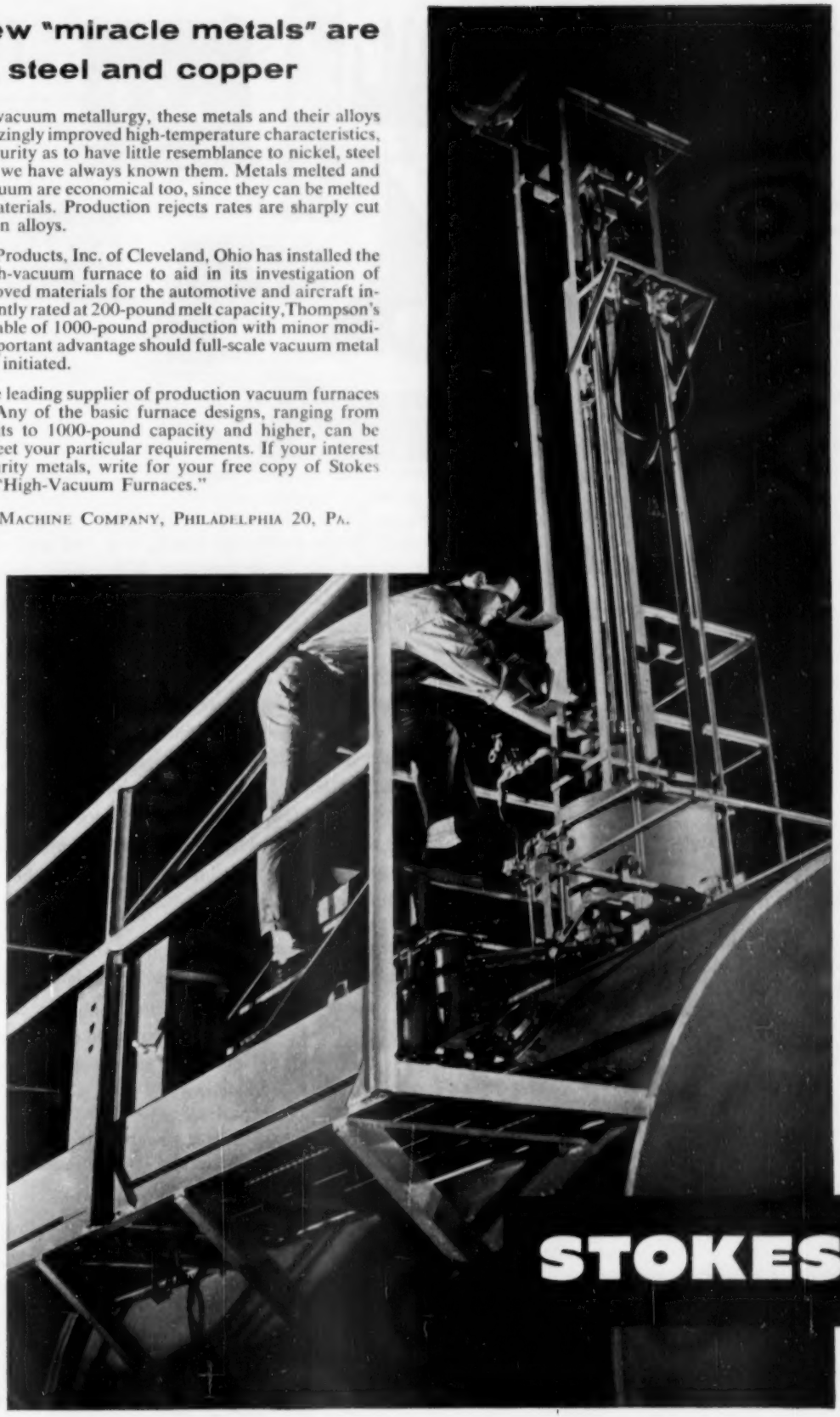

HOW TO PREDICT THE BEHAVIOR OF REACTOR COMPONENTS

In-pile irradiation testing is a vital part of any reactor development program. Such testing shows the effect of radiation plus temperature on new reactor fuels, materials, and components.

To insure the utility of these tests, *NDA* has designed and operated systems which accurately control and record in-pile test conditions. The heart of *NDA*'s system is a test capsule containing the material to be tested, a heater for accurate temperature control and monitors for determining the integrated neutron flux. This capsule is suitable for operation at temperatures up to 1800° F. in the highest neutron fluxes available in this country.

NDA offers a "package" irradiation service which includes design and construction of the in-pile test system, supervision of the irradiation test at the reactor site selected by the client, and transportation of the test sample in a shielded container to the analytical laboratory for post-irradiation examination.

Consultation on a program to meet your specific testing requirements is available without obligation.

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NDA

NUCLEAR DEVELOPMENT ASSOCIATES, INC.
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ROUNDUP of Key Developments in Atomic Energy

LATE NEWS and Commentary

Geneva Conference

With next month's Geneva atomic energy conference only weeks away, the stage has been set and the intense preparatory activity is drawing to a close. People, equipment and mountains of paper have begun to move to Geneva.

As of this writing, the vital statistics are: 66 nations have said they will send delegations, with 33 countries having submitted papers for the program. A total of 1,084 abstracts of papers were received by the UN. About 450 of these papers have been selected for oral delivery.

Best guesses are that there will be 800 official representatives of nations present. Unofficial attendants may well equal this number. **To get seating priority over the general public, unofficial visitors with a legitimate business interest in the conference should immediately contact Adrian Pelt, Director, European Headquarters, United Nations, Geneva, Switzerland.**

By now, with all papers in the hands of the UN, each nation has made the basic determination of how far it will go in revealing details about its projects. However, on-the-spot decisions to go further can be made in discussion periods after papers. This may be where the highlights of the conference will take place.

AEC chairman Lewis L. Strauss, in characterizing the U. S. contribution, said, "We're not going to Geneva to compete . . . to prove that we're better than anyone else." But he seemingly contradicted this by also saying, "For the Geneva conference there has been a reservation of information so that we could go to Geneva with a bag of tricks."

The first excitement will undoubtedly come on the second day during the plenary sessions when there will be one session with only two papers: "The first atomic power station in the USSR and the prospects of atomic power production" by N. A. Nikolayev, USSR, and "Design and operating experience of a prototype boiling water power reactor" by W. H. Zinn, et al., USA. It is not known how far the USSR will go in giving technical details on its 5,000-kw plant, but the UN has said that a film of the plant will be included in the presentation. Zinn has made the point that for the first time in talking about reactor technology he will be able to say "everything he knows about the subject."

Competition between nations will be most evident in the exhibits, both the official one at the Palais des Nations and the downtown one at the Palais des Expositions. However, it will be the downtown trade fair that will provide the key to the industrial rivalry for nuclear export business.

Eight countries have rented about 80,000 sq ft in the trade fair—U. K. (30,000), U. S. (25,000), France (17,000), Switzerland (2,750), Belgium, West Germany, Holland and Italy. Foreign exhibitors will include:

U. K.—Ekco Electronics (reactor and lab instruments); Metropolitan-Vickers (drawings of swimming pool reactors, liquid sodium pump, liquid bismuth pump, 25 Mev linear accelerator); GE Co. Ltd. (atomic power equipment); H. Tyler (glandless circulating pump); Nuclear Power Plant Co. (panel announcing formation of group comprising 8 firms to design and construct atomic power plants in any part of world); Cambridge Instru. Co. (electronic recorders, pH apparatus); Elliott Bros. (micromicroammeters, recording β/γ monitors); 20th Century Electronics (G-M counters, synchrotron guns, neutron counters); Scientific Instru. Mfrs. Assoc. (radiation monitors, oscillographs, radioactive dust samplers); Sunvic Controls (pulse height analyzer, chart recorder); Hobson Ltd. (reactor controls); Nuclear Engineering Ltd. (radiotherapy equipment using Co^{60}, equipment for irradiation of plastics); Tube In-

vestment Ltd. (tube fittings); Isotope Developments Ltd. (nucleonic instru.); Vokes Ltd. (air filters).

France—Societe Mesco (radioactivity measuring equipment); Compagnie generale de radiologie (oil diffusion pumps, diffraction chambers); Saphymo (radioactivity measurement, thickness gages); Bodson (measuring equipment); C.R.C. (electronic equipment).

Germany—E. Leybold's Nachfolger (vacuum pumps, measuring equipment); Cerberus Gmbh (electronic gas tubes). **Italy**—Societa Elettronica Lombarda (measuring equipment, uses of radioisotopes); Italettronica Comerciale (mass spectrometer, counters); Fratelli Koritsker (nuclear emulsion microscope); Officine Galileo (high vacuum pumps).

Switzerland—Moser-Glazer (nuclear measurements); Mettler (analysis scales); E. Haefely (selenium converter, cascade generator); Jaquet (measurement equipment); Sodeco (impulse counters); Landis et Gyr (electronic measuring equipment); Union Carbide, Europa.

Belgium—Union Miniere du Haut-Katanga (uranium ores, uses of radium); Physique industrielle, S.A. (Geiger counters); Manufacture belge de lampes et materiel electronique (Geiger, scintillation counters); Societe generale metallurgique de Hoboken (minerals). **Holland**—Phillips Corp. (high tension cascade generators, measurement of radiation, recording instruments, isotopes).

■

Moscow Meeting In what some interpreted as an attempt to steal some of the thunder from the Geneva conference, the USSR Academy of Sciences in mid-June invited 41 nations to a July 1–5 session on peaceful uses of atomic energy in Moscow. Many countries turned the invite down because of shortness of time and interference with Geneva work. Those who did go to meeting were shown Russian 5,000-kw nuclear power plant.

●

Livermore Reactor Foster Wheeler has been awarded the contract on the Livermore Pool-Type Reactor (LPTR) with a low bid in the range of $400–500,000. The next three bidders (Kaiser-GE, North American-Parsons, and Fluor) put in much higher offers, in the range $700–$800,000. Following them were AVCO–Vitro, Burns & Roe-AMF, and Cooke Lab.

●

AEC Regulations Two more sets of regulations under the new law have been issued by AEC—operators licenses and standards for protection against radiation.

■

Rural Power Proposal A 22-Mw nuclear power plant to serve rural needs near Minneapolis, Minn., will be built in 3–4 years if a proposal by the Elk River Cooperative Power Assoc. is approved by AEC and REA. Proposal asks AEC loan of about $3-million for construction of the reactor portion (fuel extra) and REA loan of $1.75-million for turboelectric part. Co-op estimates plant would reduce their power costs from 9.25 to 6.4 mills/kwh.

As designed by American Machine & Foundry, a 900 psi, 533° F boiling-water reactor would generate steam to produce 650 psi, 486° F saturated steam in a heat exchanger; an oil-fired superheater, supplying 20% of the total heat, would bring the steam for the turbine to 600 psi, 825° F.

AEC Operating Costs Rising to $1.9-billion

With almost all of the fissionable material production facilities now under construction slated to come into operation in fiscal 1956, the Atomic Energy Commission has told Congress it wants to spend a record $1.47-billion to operate its plants in '56. This is expected to level off at about $1.9-billion annually in 1960.

AEC has also asked for $0.27-billion for capital facilities in '56. As required by the new atomic law, this request is in the form of special authorizing legislation.

If the '56 appropriations are granted in full, a total of about $16-billion will then have been put into the U. S. atomic energy program since 1942, with slightly over 50% of this having gone into capital facilities. A partial breakdown of dollar investment in manufacturing plants shows this distribution: feed materials—$0.2-billion; reactors and gaseous diffusion plants—$4.8-billion; weapons fabrication plants—$0.4-billion.

The main increases in operating expenses in '56 result from the need to procure substantially larger quantities of uranium concentrates and the "coming on stream" of production facilities. AEC revealed that it will have eight graphite reactors running at Hanford and five heavy-water reactors at Savannah River.

Past and anticipated operating costs break down as shown in Table 1.

One interesting number contained in the budget request is $1.03-million for "classified project A," work being done under AEC's Division of Research. Reading between the lines of the report gives the indication that this money is for hush-hush work on controlled thermonuclear power. $¼-million was spent on this in '54 and ¾-million in '55.

In part, the $0.27-billion being asked for capital facilities will be spent as follows:

Production or development plants or facilities, $20,000,000; power reactor development acceleration project, $25,000,000; fast power breeder pilot facility (EBR-II), $14,850,000; surface ship reactor facility, $25,000,000; submarine advanced reactor facility, $23,140,000; submarine advanced reactor development facilities, Schenectady, New York, $3,100,000.

Also, aircraft nuclear propulsion program plant and test area, Arco, Idaho, $13,000,000; aircraft reactor test plant, $1,437,000; modifications and expansions to ANP ground test plant, Idaho, $1,000,000; special reactor facilities construction program, $2,000,000; reactor core test facility, Arco, Idaho, $600,000.

Also, particle accelerator program, $10,000,000; metallex pilot facility, Oak Ridge National Laboratory, $1,000,000; reactor facilities modifications, Hanford, Washington, $11,900,000; special reactor facilities equipment, Hanford, Washington, $5,600,000; modifications to separations and processing facilities, Hanford, Washington, $2,560,000.

Also, conversion of pilot plant and facility to production plant and facility, Fernald, Ohio, $600,000; barrier plant addition, Oak Ridge, Tennessee, $750,000; new barrier development plant, Oak Ridge, Tennessee, $404,000; expansion of metal recovery facility, Oak Ridge National Laboratory, $370,000.

Also, engineering test reactor facility, $14,350,000; reactor training school, Argonne National Laboratory, $712,000; chemistry cave for radioactive materials, Argonne National Laboratory, $448,800; reactor engineering building addition, Argonne National Laboratory, $295,000; high level chemical development facility, Oak Ridge National Laboratory, $280,000.

Also, research reactor, Philippine Government, $500,000; research reactors for the development of peacetime uses of atomic energy under Agreements for Cooperation, $5,000,000; conversion of existing building to development plant, Oak Ridge National Laboratory, $1,150,000; fabrication plant for development equipment, Oak Ridge National Laboratory, $440,000; medical research plant and facility, Brookhaven National Laboratory, $6,040,000.

Development of civilian power reactors. Fiscal '56 will see operation of the sodium and homogeneous reactor experiments, the boiling-water reactor experiment will be in its final assembly stages, the pressurized-water reactor will be well under construction, and construction will be started on the second experimental breeder reactor (NU, May '54, p. 72).

The $35.43-million estimated for this program in '56 (see Table 2) includes $10-million to accelerate the program by assisting industry and expanding AEC efforts. Assistance to industry will be provided by (a) waiving charges for loan of nuclear material for 7 years, (b) doing certain research and development work in AEC labs, and (c) contracting for technical and economic data to be derived from power demonstration reactors. For this program,

TABLE 1—Operating Costs

	1954 (actual)	*1955 (est.)*	*1956 (est.)*
Source and fissionable materials	$417,599,302	$674,919,000	$947,458,000
Weapons	218,119,230	226,386,000	271,148,000
Reactor development	87,603,074	101,095,000	134,582,000
Physical research	38,612,424	40,253,000	45,720,000
Biology and medicine	24,936,611	27,000,000	27,000,000

TABLE 2—Reactor Development Program Operating Costs

Category	*1954 (actual)*	*1955 (est.)*	*1956 (est.)*
Civilian power reactor development	$18,974,600	$25,804,000	$35,430,000
Army power reactors	0	678,000	2,100,000
Naval propulsion reactor program	26,498,081	28,270,000	34,268,000
Aircraft propulsion reactor program	14,572,118	21,575,000	37,900,000
Special classified projects	7,607,638	6,159,000	7,200,000
Advanced engineering and development	12,104,427	12,874,000	11,950,000
Operation of service facilities	7,846,074	5,735,000	5,734,000
Total	$87,603,074	$101,095,000	$134,582,000

the budget provides $50-million under the "operating expenses" appropriation for obligations in 1956. It is estimated that costs to be incurred during 1956 will amount to $10-million, the balance being included in unpaid obligations at the end of fiscal 1956.

The Commission's own power-reactor development program shapes up as follows:

Pressurized-water reactor. Spending for this reactor in '56 will decrease from '55's $9.48 to $7.5-million. Installation of equipment, core fabrication, and fuel-handling facilities will start and orders for final components will be placed. Core design, reactor physics and experiments will involve $2.73-million; core materials development, $2.27-million; plant components development, $1.35-million; development of over-all plant control and instrumentation, $1.15-million.

Boiling-water reactor. The estimated $3,817,000 spent during fiscal '55 on this reactor will increase to $4.5-million to support the following: construction of boiling-water experimental reactor plant, $2.21-million; development and design of boiling-water experimental reactor, $610,000; fuel-element development in connection with full-scale reactors, $500,000; design and evaluation of fuel alloys that are corrosion resistant in high-temperature water and can be fabricated for use in water-cooled power reactors, $600,-000; boiling investigations including heat transfer, fluid flow, scale deposition, entrainment, etc., $450,-000; control evaluation and design, $130,000.

Homogeneous reactors. With total cost of the homogeneous-reactor test (HRE-2) expected to cost $1,825,000, spending on the general homogeneous-reactor program will step up from $6.6-million in '55 to $7.2-million in '56. Progress on design studies, chemical problems, and reactor physics are expected to permit formulation of plans for the large-scale homogeneous reactor during 1956. Expenditures during the coming year break down as: laboratory research and development, $6.36-million; design, fabrication, and installation of HRE-2, $490,000; operation of HRE-2, $350,000 (compared with '55 spending of $5,265,000, $1,335,000, and 0, respectively).

Fast power breeder reactor. Major decisions on this system are expected during 1956 as $4.13-million (vs. $3.66-million in '55) is spent on: engineering design and development of EBR-2, $3.1-million; development of EBR-2 components, including mockups and testing $855,000; fast critical experiments, $620,000; ANL design, $505,000; other engineering design and development work, $1.12-million; reactor fuel development, fabrication and tests of fuel elements, $500,-000; structural materials development $175,000; chemical processing, $355,000. The increase is due largely to large-scale components tests that will demonstrate all major plant operations including the reactor, fuel processing, coolant system, and special power equipment.

Sodium-graphite reactor. With about half the $3.5-million total cost of the fabrication and equipment being spent in '55 and the other half in '56, AEC spending on operating this project will decrease from $2,252,000 in 1955 to $2.1-million in 1956. Similar spending by North American Aviation, Inc., will be $1,221,000 and $658,000. Research, design, and development will entail $1.06-million, and fabrication (including NAA capital expenditures) will involve $1,698,000 in '56; in 1955 these items will involve $1,597,000 and $1,876,000, respectively.

Army power reactors. APPR-1 is the first step in development of package power reactors for military use. Heterogeneous boiling reactors and gas-cooled reactors, as well as radically new low-power reactors, will be studied. Experiments will be made on boiling homogeneous reactors. Expenditures in '56 are expected to be: boiling package reactor, $178,000; low-power reactors, $472,000; gas-cooled systems, $500,-000; pressurized-water systems, $950,000 (compared with '55 spending of $55,000, $150,000, $100,000, and $373,000 on these items, respectively).

Naval propulsion reactors. Increases in this program, which includes STR-1, STR-2, SIR-1, and SIR-2, are due to initiation of work on advanced reactors for submarines and other new projects. Development items include: research and development on the initial projects (STR and SIR), $9.95-million; operation of experimental prototypes (STR and SIR), $5,029,000; fuel fabrication for STR and SIR, $3,-794,000; research and development on new projects, $14,545,000; fuel fabrication for prototypes for new projects, $950,000.

U. S. Pushes Ahead On Bilateral Agreements

The atom is going abroad, under strict U. S. supervision. June saw a score of bilateral agreements signed with friendly foreign nations, a move which should shoot this country far out in front in the international cold war.

Bilateral agreements are provided for in the 1954 revision to the Atomic Energy Act. They're an important part of President Eisenhower's Atoms-For-Peace Plan and the only part of it that will get general support in Congress.

That's because the other half of the plan—establishment of an independent international agency under United Nations auspices—involves possible surrender of United States control over materials and information this nation may supply for the Atom Agency's proposed "pool." There's a sizeable bloc of senators and congressmen who oppose this.

Three of the bilateral agreements initialed by mid-June—with Belgium, and Canada and the United Kingdom—call for exchange of classified data. One is for sale to the Swiss of the display research reactor we will put up at the August Geneva Conference. The remainder are identical; they feature lease of small research-reactor amounts of fissionable materials and exchange of unclassified information. All permit U. S. businessmen to participate in exporting and importing materials and equipment and to supply services for foreign firms and nations.

The administration is pushing the bilateral aid program because terms are sharp and clear when agreed upon by only two parties. There's no question of a majority vote overriding the U. S. This allows us to attach plenty of strings to our offers of aid to make sure no special nuclear materials or classified information will filter behind the iron curtain.

Britain, Canada and Belgium contributed much to development of the A-bomb during World War II. The first two were intimately associated with the Manhattan project, and Belgium's Congo uranium fueled the bombs which are credited with speeding the end of the war in the Pacific.

Therefore, the contracts with these three nations are far more liberal than the others signed so far. For the same reason, you can't regard them as prototypes of subsequent agreements calling for U. S. disclosure of classified information. We may agree in the future to supply other friendly nations with restricted data, but odds are these would not be as liberal as the ones just signed with Britain, Canada and Belgium. In these cases, we're paying a debt, so to speak.

Debt or no debt, there are strings attached to even these three offers. Let's look at some of their terms to see where:

• Great Britain—the U. S. will not supply special nuclear materials. The British have their own. We will not exchange restricted data which is primarily of military importance. This includes for the moment classified information pertaining to submarine, ship, aircraft and "certain package power reactors." When AEC decides these reactors warrant peacetime application, exchange of information may be worked out.

All restricted data to be supplied one country by the other must be relevant to current or projected programs. Restricted data on specific power reactors won't be exchanged unless the reactor is currently in operation in the receiving country, or unless it's being seriously considered for building. Enough data will be supplied on which to base decisions as to whether to build them.

No privately-developed or privately-owned information, or data received from another government, will be exchanged.

What we will exchange with the British is information on:

Reactor physics, reactor engineering, properties of reactor materials, specification for reactor materials, reactor components, overall design and characteristics and operational techniques and performance of all types of reactors, uranium and thorium technology, properties of all materials, technology of production and utilization of materials, health and safety.

We will supply materials for research work to accompany information on any of the above subjects if such materials are not available commercially to the British, and vice versa. Equipment and devices of

About the Industry

Manufacturers of radioactive products can get public liability insurance that includes coverage for damage claims arising out of use of a product. One of the first such policies was recently issued to Technical Operations, Inc., Arlington, Mass., producer of encapsulated radioactive sources for industry and medicine.

Indemnity Insurance Co. of North America wrote the policy on a standard products liability form. Face amount of the policy is said to be under $500,000. Premium rate was not revealed.

Bear in mind that this amount is far from the multimillions now thought necessary to cover a nuclear power plant. Also, use of a sealed radioactive source can be made much less hazardous than use of unsealed products or wastes.

Expect profits from nuclear power activities to be restricted for about 10 years. That's what Alfred I. Iddles, president of Babcock & Wilcox Co. told his stockholders recently. Research and development costs will be high, reducing profits, he said.

There's evidence of B&W's faith in long-term profits as a nuclear power plant designer and fabricator, however. The company's Atomic Energy Division has been increasing its personnel; more than 100 scientists and engineers are now employed. And B&W is building a plant at Lynchburg, Va., for manufacture of fuel elements and other reactor components.

Radiation warning signs may become an industrial problem. Industrial representatives attending a hearing on a proposed New York State radiation code protested that the word "danger" on radiation warning signs could create an unfavorable public and worker reaction. They suggested that the conventional magenta propeller on a yellow background be accompanied by a phrase like "radiation—take proper precautions."

These protests and suggestions are mild. More vehement are the reactions to a warning symbol that the chemical industries committee of the International Labor Organization wants adopted on a worldwide basis.

The proposed ILO symbol consists of a square, with a box slightly below center. The box, black with a big white "R," has dotted lines radiating from it. The lines diminish in thickness farther from the box. So far, so good.

What bothers industry most is the grinning skull and crossed bones situated just above the box. This is the symbol usually associated with poison.

Basic to the entire problem is public education. If the public were as accustomed to radiation as they are to iodine in their medicine cabinets, there'd be no worry about symbols. Said one industrial spokesman, "We can't expect government to listen to our ideas about warning symbols until we assume part of the burden of public education about radiation."

A new growth-type mutual fund has been formed in Philadelphia. Science & Nuclear Fund has been offering shares at $10.99; from one to two-thirds of its assets will be invested in nuclear-science concerns. Stanford Research Institute has been retained as technical consultant.

nonmilitary character will also be exchanged under specific agreements.

Neither nation may use exchanged material or equipment for military purposes, or transfer it to other nations without approval.

The pact is for 10 years.

• Canada—In general, this is similar to the British Agreement. But with these differences:

We agree to sell Canada as much uranium enriched with U-235 as she needs in her power reactor program up to the point where AEC considers the amount of military significance; we'll exchange information on military nuclear power plants insofar as it furthers our joint early-warning radar network; we will not communicate data on design, construction and operation of production plants for separation of U-235 from other uranium isotopes, or for separation of deuterium from hydrogen until Canada decides to build hydrogen separation plants; we will supply heavy water; research and reactor testing facilities will be mutually available, except those of primarily military significance; Canada must offer the U. S. first choice of any special nuclear materials when produced from irradiation of fuel elements enriched with U. S.-supplied U-235; existing U. S.-Canadian agreements on intertransfers and sales of uranium, plutonium, heavy water and other materials will continue in effect; as in the British agreement, mutual patent rights will be extended.

• Belgium—this agreement is unique. It does not provide specifics on information and materials exchanges in such great detail as the British and Canadian pacts, and emphasis is on Belgium supplying us with raw materials and the U. S. supplying Belgium with technical information and manufactured materials. It is stated at the outset that Belgium will receive data and materials "on terms as favorable as any other major uranium supplying country except Canada."

The U. S. will supply: U-235-enriched uranium for research and power reactors, plus classified and unclassified data similar to that going to Britain and Canada; training for their scientists and engineers; aid in building and operating a PWR when they decide to build one, and aid in building other types when and if AEC decides they're commercially valuable.

Reactor News

First fuel fabrication license asked. Metals & Controls Co., Attleboro, Mass., has made the first application for an AEC license to fabricate nuclear power plant fuel elements. Babcock & Wilcox had previously announced its intention to build a plant, but has not yet applied for a license (NU, April '55, p. 74).

Britain speeds nuclear power program, starts new test reactor. Although construction is due to start on two of Britain's gas-cooled nuclear power stations in 1957, D_2O-cooled units likely will be started in '58 and '59 instead of several years later as originally scheduled (NU, March '55, p. 7), according to Sir John Cockcroft. He also predicted that costs will drop faster than anticipated in last winter's announcement of Britain's nuclear power development plan.

Each of Britain's first two commercial nuclear plants (to be started in '57) probably will use two improved Calder-Hall-type reactors to develop about 150-Mw (elec.); fast flux will be about 10^{13}. Each plant will cost $42–56-million—about the same as the 50-Mw Calder Hall plant. The CO_2 coolant in the two Calder Hall reactors will be at 90–100 psi; design operating temperature is 400° C. Presumably, fuel elements are clad with magnesium alloy.

The Atomic Energy Authority also is stepping up development of breeders and light- and heavy-water units, as well as homogeneous reactors. For testing materials and components for these, AEA is building a second heavy-water reactor (construction of the first, E-443, was started some time ago). Designated RE-773, the new reactor will have a high flux that will cut average irradiation time from a year down to 10 days; its eight temperature-controlled test loops will cost $70,000–$140,000 each.

Belgian industrial group plans reactor. A group of undisclosed industrial firms in Belgium is planning to start building a 75–100-Mw reactor in 1958; completion is scheduled by 1960.

Canadian power prototype to be located 10 miles from Chalk River. Canada's 20-Mw Nuclear Power Demonstration Reactor (NPD) will be built near the hydro generating station at Des Joachims along the Ottawa River (NU, April '55, p. 11). The property is owned by Ontario Hydro, which will contribute $3–3.5-million to the $13–15-million project. With the Canadian government share at $7–8-million, Canadian General Electric Co.'s tab probably will equal Ontario Hydro's.

Norway plans 20-Mw power reactor. Three years is the target date for completion of a 20-Mw reactor for Saugbruksforeningen, a wood-processing firm in Halden, eastern Norway. It will cost about $3.5-million, including uranium and D_2O, and will be designed at Kjeller.

No news on demonstration proposals. It may be months before AEC announces its decision on the four power demonstration reactor proposals it received April 1. Insufficient data, particularly on reactor safeguards, has been submitted by the applicants, says AEC. The vagueness of some of the plans, which were rushed in to beat AEC's deadline, is adding fuel to the fire critics of the demonstration program have built.

GM in nuclear business? It appears that General Motors is getting into the reactor field in a substantial way. GM has hired L. R. Hafstad, former AEC reactor chief and, for the past six months, adviser on atomic energy at Chase Manhattan Bank. Although he will be director of research, it can be expected that Hafstad will help crystallize GM thinking on nuclear business. A prime GM competitor, Ford Motor Co., has been active in atomic energy for some time, particularly last year when it had a $75,000 contract from the Detroit Edison nuclear group for fuel-element fabrication. In addition, Ford has just announced a $100,000 nuclear power study project.

Belgium agrees: to give us first option on 90% of the uranium and thorium ore and concentrate output of Belgium and the Congo in 1956 and 1957, and 75% during 1958, 1959 and 1960; to extend this same option to cover raw materials used to supply Belgium with U. S.-processed special nuclear materials; to confer on percentages to go under first option after 1960.

Both nations agree to exchange general economic and technological data on research and power reactor programs.

• Switzerland—no classified information to be exchanged. The Swiss will buy the U. S.-built Geneva research reactor for $180,000, be supplied fuel to run it, and exchange unclassified research reactor data with us.

• The Philippines, Greece, Nationalist China, Portugal, Holland, Denmark, Turkey, Brazil, Colombia, Lebanon, Israel, Argentina, Italy, Spain, Venezuela, Japan, Uruguay, Chile and Pakistan—under these, the U. S. will supply technical aid and fuel for each to build a research reactor. Fuel is limited to 6 kilograms (13.2 lbs) of contained U-235 in uranium enriched up to a maximum of 20% U-235 outstanding at any one time. We will process fuel elements, and supply substitute fuel while processing and shipment take place. No classified information is involved.

It is expected that a number of this last group of nations will benefit from the U. S. offer to underwrite half the cost of research reactors they may build. One nation, the Philippines will receive the total cost, $500,000, as a gift.

67 Get Access Permits in Two Months of New Plan

Industrial response to AEC's simplified procedures for gaining access to classified data related to civilian uses has been immediate. By May 31, slightly less than two months after the program started, 67 permits had been granted to organizations and individuals. Some of these, however, were transfers from the old access and study agreement program.

Permit holders have to get either an "L" or "Q" clearance for their personnel, depending on whether access is wanted to confidential or secret data.

Industrial Applications

How close are we to commercial use of radiation treatment to stop potato sprouting? Encouraging results on irradiating potatoes to stop sprouting and resultant storage loss—estimated at millions of dollars yearly—have not yet enticed industry into starting its own development program. Much test work on wholesomeness of low-dosage potatoes has to be done before the Food and Drug Administration will approve them. Economics look very good, but thus far designs are only on paper.

Potato irradiation was interesting enough to draw 137 people from potato processors and growers, universities and research sites, industry and the military, to a conference that Brookhaven National Laboratory sponsored on May 25. Transcripts of the conference are available from A. H. Sparrow, BNL, Upton, N. Y.; but this column is based on what was said both at the conference and at supplementary talks afterwards.

Need for treatment. Of the 3.5×10^8-bushel annual crop, about 80% is harvested in Sept. and Oct. Deducting for the potatoes held in good refrigerated storage and those used quickly, about $4–5 \times 10^7$ bushels is the annual potential volume for treatment. Irradiation treatment is by far the best means available of inhibiting sprouting.

Gamma or beta rays are usable. Doses of 10,000–20,000 rep of gamma rays are known (NU, Aug. '54, p. 16) to stop sprouting for 18 months. Room-temperature storage, although not completely investigated, is possible for long periods after such treatment. Latest research, (to be published in NU) shows that electrons also stop sprouting. Penetration is only about 1 mm, but this is enough to disrupt the sprouting mechanism. Tubers have to be turned or irradiated simultaneously from opposite directions so entire surface receives 10,000–20,000 rep.

Costs of radiation processing. Electron accelerating machines are available at about $1/equivalent curie, but no designs using them were presented. Present price of cobalt-60 is $5/c, but may come down to 15¢/c. A truck-mounted potato irradiator would irradiate 0.6 ton/hr to 12,000 rep. Total operating cost would be ½¢/lb. Estimates on a plant to process 15 ton/hr to 10,000 rep indicate 1.5¢/lb total cost. One figure to compare with treatment costs is 2.5¢/lb for shipping potatoes from Florida to Detroit.

Potato quality and acceptability. Professional taste panels of General Foods Corp. have been unable to detect any difference between unirradiated tubers and 21,000-rep irradiated tubers. The FDA feels that extensive feeding tests are needed to prove safety of irradiated potatoes. Many authorities feel that there is no possibility of deleterious substances forming at the low sprout-inhibition dose (NU, June '55, p. 17). But tests are needed on possible changes in potatoes upon storing them for a year or more, as this never has been possible before. One research site has applied for Quartermaster Corps funds to make this type of test. Test would be conducted in a manner similar to U. of Michigan's present studies on 4×10^6-rep treated foodstuffs. Engineering counterpart of feeding tests, a pilot plant, is also sorely needed.

ROUNDUP

News in Brief

Fulbright award applications for 1956–1957 are due October 1. Included in the government-supported program for lecturing in foreign universities are: medical uses of atomic energy, U. of Brussels, Belgium; nuclear physics, U. of Helsinki, Finland; theoretical physics, Grenoble, France; physics, Darmstadt, Germany. Advanced research programs include: theoretical physics, Institute for Theoretical Physics, Copenhagen, Denmark; nuclear energy, U. of Oslo and Joint Establishment for Nuclear Energy Research, Norway. Write Conference Board of Associated Research Councils, Committee on International Exchange of Persons, 2101 Constitution Ave., Washington 25, D. C., for more information.

Forum membership more than doubles in year. Atomic Industrial Forum now has over 300 member organizations. Included are organizations from Great Britain, France, Switzerland, Belgium, Sweden, Italy, Canada, Mexico, and Brazil. Bulk of membership is still U. S. organizations.

Hans Thirring will discuss peaceful thermonuclear reactions at NICB meeting. Fourth annual National Industrial Conference Board meeting in New York, October 26–28, will include talk by director of Institute of Theoretical Physics, Vienna, Austria, who was one of first to write publicly of thermonuclear weapons. Now Thirring will discuss nonweapons potential.

New UCLA cyclotron will fill gap at 50 Mev. Present accelerators jump in design energy from 20 Mev to 150 or more, leaving a hole in nuclear scattering data. University of California at Los Angeles plans to have a 49-inch 50-Mev unit completed next spring. Magnet of world's first cyclotron (41 inch, 20 Mev) will be used as analyzing magnet for new $50,000 unit. K. MacKenzie, B. Wright, and J. R. Richardson of UCLA physics department are directing project. Office of Naval Research is cooperating.

IRE Professional Group on Nuclear Science invites papers for second annual meeting at Oak Ridge, Sept. 14–16. Abstracts of 200 or fewer words should be sent to H. E. Banta, Oak Ridge National Laboratory, Box P, Oak Ridge, Tenn., by July 15. Suitable subjects include reactor electronics and controls, accelerator electronics, medical instrumentation, multichannel analyzers, radiation detectors, radiation damage of electronic components, and electronics applied to research. Institute of Radio Engineers group is planning tours of Oak Ridge facilities at time of meeting.

Los Alamos marks tenth anniversary of first nuclear detonation. Classified material is being removed from a number of sites and new facilities so that an open house can be held July 16–17, ten years after the Alamogordo test. Families of employees, other Los Alamos residents, news media representatives, science staffs of New Mexico colleges have been invited to visit the 77-square mile technical area. It's the first time the area has been opened generally since the laboratory was started in 1943.

Britain building irradiation cells for fission-product use. Industry will be able to use facilities for research and processing. The cells are being built near nuclear power plant at Sellafield. Program is aimed at establishing an industry based on byproduct wastes from power reactors Britain is planning. Observers say British lead U. S. in applications to plastics, but lag in use for food and drug processing.

ANS plans hot lab, international meetings. Working with the AEC project hot laboratory committee, the American Nuclear Society will sponsor the fourth meeting on hot lab design, operation and equipment at the Sheraton Park Hotel in Washington, D. C., Sept. 29, 30. At the same hotel, ANS will cosponsor an international meeting (with reports out of Geneva by a number of countries) with the Atomic Industrial Forum, the evening of Sept. 28 and all day Sept. 29. The Forum Trade Fair will also be in progress at the Sheraton Park during the entire week.

Nuclear exhibits urged for power show. American Society of Mechanical Engineers, celebrating its 75th anniversary, is adding an extra Exposition of Power to the usual biennial schedule. Show will coincide with annual ASME meeting Nov. 14 to 18 in Chicago. Atomic power section is planned for show, and ASME's nuclear engineering division will present program of technical papers.

North American building nuclear research laboratory. Vinnell Company will complete construction of the over $1-million building in Canoga Park, Calif., in October. Only engineering and small-scale radioactive research will be carried out at this site; heavy nuclear research and development work will be carried out by the newly formed nuclear engineering and manufacturing department. Later will move from Downey, Calif., to North American's propulsion field laboratory in the Santa Susana mountains.

Nuclear Engineering and Science Congress will hear nearly 300 papers. Cleveland meeting, December 12 through 16, will have 50 sessions. Authors of papers represent 24 business and technical societies that are sponsoring meeting, 16 universities, 13 government bureaus and AEC contractors, and 34 major U. S. industrial corporations.

Bank hires Stanford Research Institute to report on atomic developments. Bank of America president S. Clark Beise says atomic energy is "already a factor in our economy." SRI will also study industries bank is dealing with.

American Radiator and Standard Sanitary Corp. forms atomic energy division. Headquarters will be at Redwood City, Calif., where company has a research laboratory. F. A. Parker will head new division, with D. J. Mallon as director of research. Company is aiming at effective manufacture and eventual design of complete primary reactor systems. Three divisions already make reactor components.

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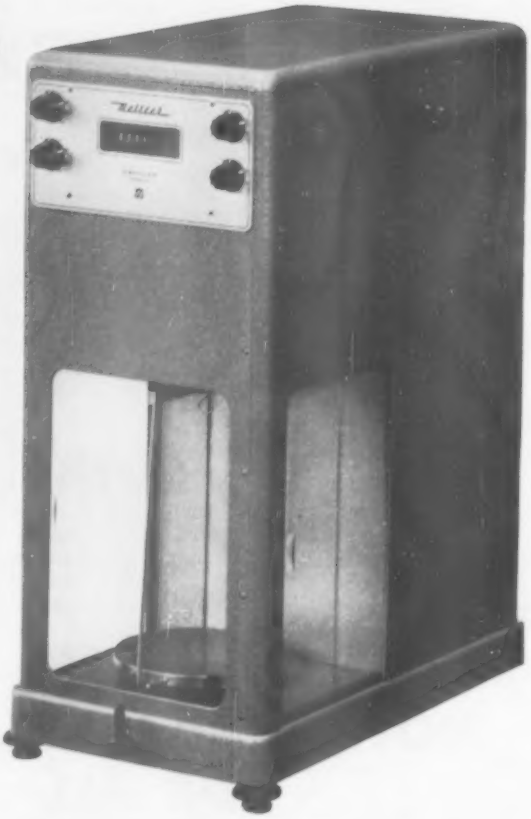

This balance, of course, can be operated by hand in the conventional manner, but, the same as the standard METTLER analytical model of 200 g capacity, is very well suited for operation by master-slave manipulators.

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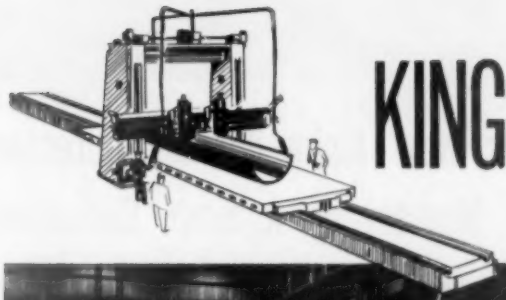
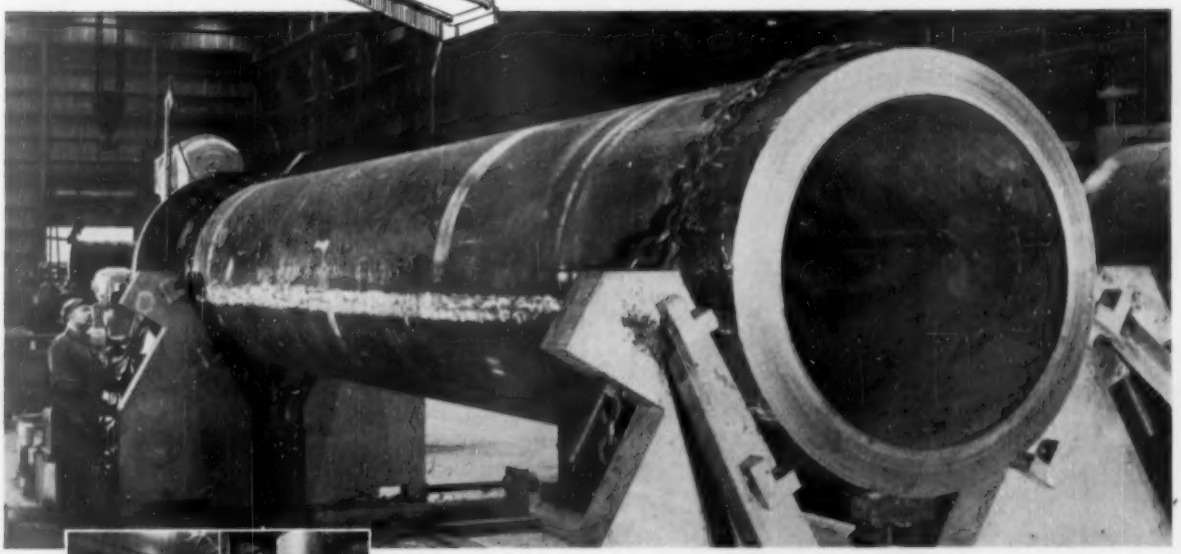
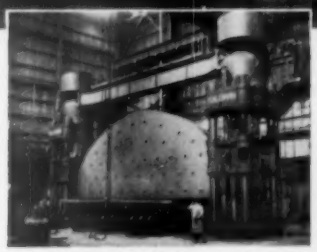
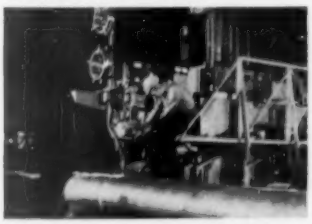


KING SIZE PRESSURE VESSELS

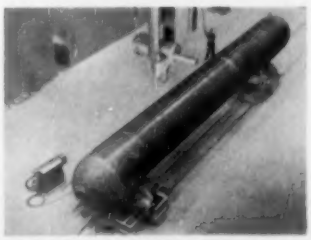




This 8,000 ton hydraulic beam press at Mountaintop can bend steel plate 39 ft long and up to 9 inches thick.



Twin-arc welding units on traveling booms permit welding of vessels up to 8 inches thick, 12 ft in diameter and any desired length.



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G.E. Designs New Alpha Particle Detector for Health Monitoring Against Radiation

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COMPACT CONSTRUCTION consists of a zinc-sulphide phosphor, photomultiplier tube and cathode follower pre-amplifier giving 0.25 volt output pulses. These pulses are transmitted to a scaler or rate meter. The detector also makes a rapid and sensitive survey meter when connected with a simple audio-speaker, which produces an audio "popping" noise.

PRICE is $249.60* and the detector is available from stock. For further information contact nearest G-E Apparatus Sales Office, or write for Bulletin GEA-6117, Section 605-81, General Electric, Schenectady 5, N.Y.

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GENERAL ELECTRIC

How Radiotracers Are Used in Measuring Fluid-Velocity Profiles

New tracer technique determines velocities within 0.002 in. of the wall—much closer than other methods—in velocity-gradient studies. Instruments used record 10^4-fold range in counting rate without need for changing scaling factor or chart speed

By FRANCES M. RICHARDSON, J. K. FERRELL, H. A. LAMONDS, and K. O. BEATTY, Jr.
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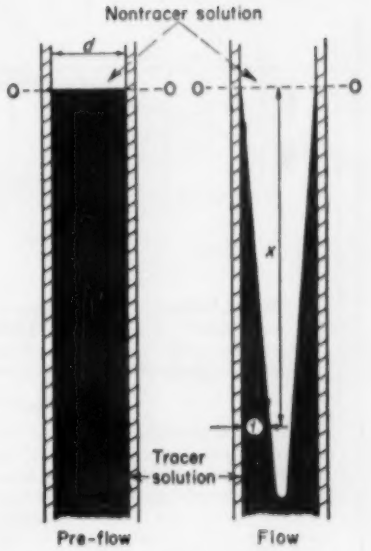


FIG. 1. "Stringing out" effect caused by variation in flow velocity across tube is the basis of tracer-displacement method for determining velocity profile. When flow starts, tracer in center of tube is displaced faster than tracer near tube wall. Radiation detector monitors the activity decrease, which is related to thickness of remaining tracer

VELOCITY PROFILES can be determined without probes in the fluid by using radiotracers. The technique described in this article—principles, equipment, results and limitations—allows direct velocity measurements within 0.002 in. of a circular tube's wall. Closer measurements are obtainable since molecular diffusion is the ultimate limit.

Each section of a flowing fluid moves at a different velocity, fastest at the center and slowest near the confining wall. Measuring the velocity-distribution profile in a flowing fluid has been a research objective for nearly 100 years. Most measurements have used pitot tubes or hot-wire anemometers to traverse the fluid and determine local velocities. Despite many efforts to minimize flow-pattern disturbances by the measuring device, disturbance is inherent in such techniques. In shear flow where the principal area of interest is the thin slow-moving wall-adjacent boundary layer, the limitations of probes are especially acute.

Basic Principle

Basics of the tracer-displacement procedure are relatively simple and may be followed in Fig. 1. The lower part of a vertical tube is filled with tracer solution, and the part above is filled with tracer-free solution. Flow is brought quickly to a constant velocity, and as the tracer-free solution displaces the other, counting rate decreases at a detector downstream from the interface. As displacement is more rapid near the tube's center, the detector sees a continuous reduction in tracer-layer thickness. Mathematics of the situation are:

At distance x downstream from the original interface 0–0, the relationship between velocity, x/t, and tracer-layer thickness, y, at any time, t, can be expressed, for pure laminar flow in a circular pipe, as

$$v/v_0 = 4[y/d - (y/d)^2] \qquad (1)$$

where v is velocity at the inner edge of the y layer; v_0 is maximum velocity present (center of the stream); and d is pipe diameter. For circular pipes

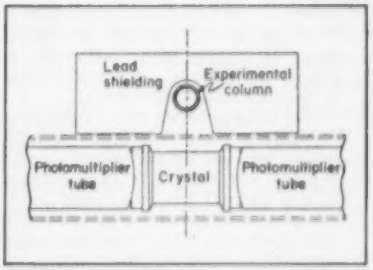
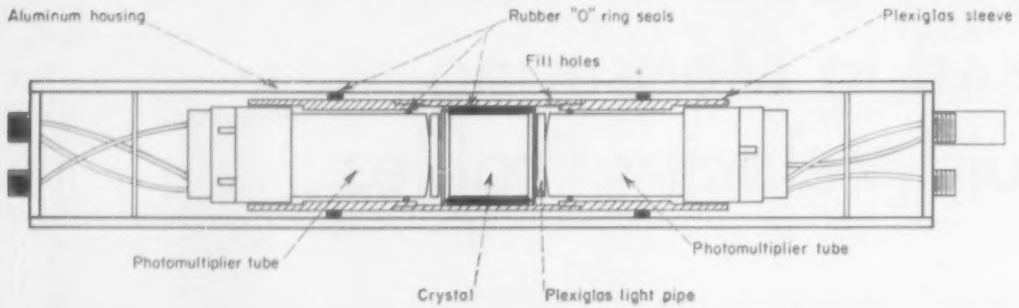


FIG. 2. Shielding of 2-in. of lead around special counter allows measurement of very thin layers of tracer solution

Wide-Range Dual-Photomultiplier Scintillation Counter



SPECIAL DETECTOR DESIGN uses two RCA photomultiplier tubes that view one NaI(Tl) crystal, 1⅝-in. diameter by 2-in. long. Crystal is enclosed in 0.025-in. spun aluminum can with an ultraviolet-transmitting glass window at each end. Crystal and tube are joined by Plexiglas light pipes ground and polished to fit the surfaces. A 2-in. Plexiglas tube filled with 200,000-centistoke viscosity Dow 200 silicon fluid—for optical contact—encloses optical assembly

Continuous recording of a range of counting rates from background to 320,000 cps is done with this system (*2*). The figures show the housing used to hold two photomultiplier tubes that view a single crystal and a block diagram of the circuits used.

One circuit measures the average anode current of one photomultiplier tube. The second photomultiplier-tube output actuates a pulse-counting system. This design makes accurate radiation-intensity measurements possible during high activity (using overall current output) and during low activity (using individual pulses).

If current and pulse rate have a linear relationship to each other throughout the counting range, it is possible to obtain an accurate record of the activity range by correlating the two indications, counting rate and current, to form a single overlapping record. The relationship proves to be linear for rates up to about 320,000 cps. Above this rate nonlinearity is caused primarily by deadtime losses in the pulse-counting system.

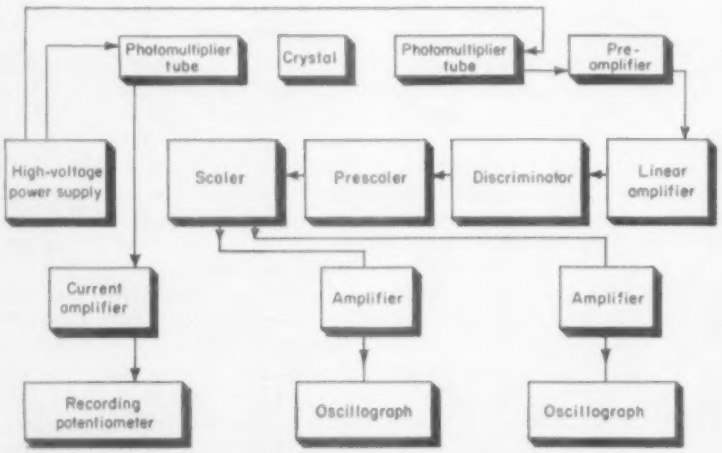
The pulse-counting branch includes a cathode follower of conventional design followed by a feedback amplifier with a rise time of 0.15 μsec and a gain of about 3,200. For our system the discriminator circuit must have a very short resolving time. Resolving time of our unit is about 0.2 μsec. The circuit is a modification of the conventional Schmitt circuit.

A fast prescaling unit inserted between the discriminator and a commercial scaling unit allows fast scaling and increases total scaling factor. This prescaler is a binary scale-of-eight unit built according to a slightly modified design of a Chalk River circuit (*3*). Resolving time is 0.25 μsec. Pulse scaling is completed by an Atomic Instrument Company basic-model 1030 scaler with a maximum scaling factor of 4,096. By combined use of the scaler and prescaler, it is possible to have an overall scaling factor of 32,768.

To continuously and accurately record and totalize the entire range possible with this high factor it is desirable to obtain a record of the photomultiplier-tube output at two different stages in the scaling process simultaneously. This eliminates the need for switching either the scaling factors or recorder-chart speeds during a run. When the radiation intensity is high a large scaling factor is needed to allow the recorder to produce a legible trace. When the level approaches background a small scaling factor is desirable to maintain a rather short time between recorded pulses. Such double observation is easily accomplished by tapping early scaling stages so that an auxiliary output scaled by geometrical factors of 4–2,048 also can be recorded.

The high scaling factors obtained from this system allowed using a conventional ink-writing magnetic oscillograph for recording. A Brush BL 202 double-channel oscillograph was used. With this it is possible to record both primary and auxiliary pulse outputs on the same recorder. The recorder is accompanied by a Brush BL 932 amplifier for the low-scaling-factor channel and by a single two-stage amplifier for the high-scaling-factor channel. An "event" marking circuit is included to mark the chart when actuated by a signal at the start of a run.

The current-measuring branch of the counter includes a 100% feedback amplifier with decade ranges, allowing measurement of 10^{-9} to 10^{-3} amp, full scale. This amplifier has negligible gain drift and a zero drift of about ±0.3% in 4 days. Amplifier output actuates an indicating meter and a 10-mv potentiometric recorder. Here again the start of a run is marked on the chart by an event marker.



SEPARATE CIRCUIT FOLLOWS OUTPUT of each photomultiplier tube

the counting rate at x is calculated

$$C/C_0 = 4[y/d - (y/d)^2] \qquad (2)$$

where C is counting rate at time t, and C_0 is counting rate with the tube full of radiotracer before flow has started. From Eqs. 1 and 2 velocity distribution may be found from counting rate.

Methods and Equipment

An isotope detectable through the confining wall must be used in this technique. Sodium-24, with 1.4- and 2.8-Mev γ-rays and a 15-hr half-life, is the tracer used. To get statistically significant counting rates with a very thin layer of tracer, it is necessary to use high specific activity solutions. This means that counting rate when the tube is full will be very high, while as flow progresses, the rate may decrease to background. The counting instruments must detect and record this entire range of activity. The system described at the left is designed to do this.

Technique used. Flow runs were made in a 0.5-in. diameter vertical column, fed from a constant-head tank. (Dye studies using the same general principle are also being carried out.) The column consisted of a glass center section joined to brass end sections above and below by glass-to-metal adapters. Tracer solution was in the middle of the glass section, separated from inactive solution on either side by two plastic sliding-block devices. The three column sections could be filled through the devices and then quickly and easily joined just before a run. Specific activity of the solution was 0.05–0.16 mc/ml. Total volume of tracer solution was 150 ml.

One counter was mounted as shown in Fig. 2, 1-ft below the top active-inactive liquid interface. The detecting unit was mounted opposite an opening in the shielding that exposed 2 in. of the glass tube. Because of the symmetry of this arrangement, the radiation entering the crystal from the solution above and below the opening has little effect on the relative counting-rate change. The ratio of counting rates corresponds to the average value at mid-position of the opening.

A second counter was mounted 2.5 ft below the top interface. Data obtained simultaneously from these two counters serve as a check on possible disturbed interfaces, instrument performance and diffusion effects.

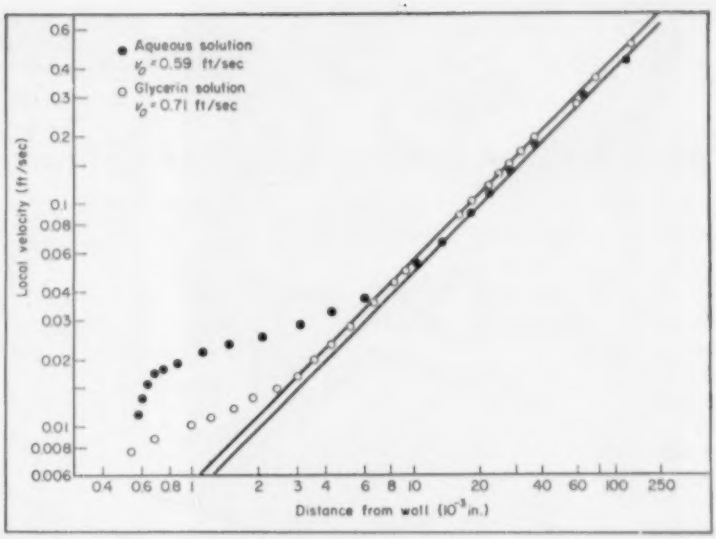


FIG. 3. Deviations from calculated velocity distribution occur close to the wall in these plots. Although horizontal scale is marked in distance from tube wall (thickness of tracer layer), it actually is ratio of counting rate at any moment to rate with tube full of tracer

Before a run, the column is filled with liquid and allowed to stand for at least 30 min to insure thermal equilibrium. Counting is begun just before starting flow and is continued until counting rate drops to a constant level. Usually this is 25–50 cps. Natural background is less than 15 cps. The difference is probably caused by a very small amount of Na absorption on the tube wall. The error involved is <0.0002-in. of undisplaced tracer solution. Time for a run varies with flow conditions and solution viscosities. Using aqueous solutions, our run times averaged 3–5 min.

Experimental Results

Results are typified by the data shown in Fig. 3. From Eqs. 1 and 2, the straight lines represent the theoretical laminar distribution for the calculated maximum flow velocities indicated. The data shown are selected values from the continuous current record of the counting apparatus. For the runs made thus far (*1*) the tracer solutions used had a specific activity low enough that the entire velocity profile was followed independently by each of the measuring branches of the counting instrument. Thus records from both branches could be compared and also considered as a single overlapping record.

Limits of error. When aqueous Na_2CO_3 solution is used, the curve follows the predicted pattern until about 0.01 in. from the tube wall. At this point the tracer thickness becomes less than would be expected for a given calculated velocity. When aqueous glycerin solution is used, the same general shape is noted but the deviation occurs at a thinner tracer-layer thickness.

The effect noted can be ascribed to diffusion of the tracer into the nontracer stream. Molecular diffusion in particular causes this variation from theory. In the glycerin solution with about 29-centipoise viscosity, diffusion is slower than in the water solution, with about 1-centipoise viscosity. Experimental results agree with the diffusion theory. Diffusion represents the real error in the data, since the counting-rate measurements are continuous, and by recording a large number of points, the statistical error may be reduced almost to insignificance.

* * *

This article is based on work performed with the sponsorship of Wright Air Development Center under Contract No. AF 33(616)-31. This support is gratefully acknowledged.

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Tenth-Value Thicknesses for Gamma-Ray Absorption

By JOHN MOTEFF
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General Electric Company
Cincinnati, Ohio

FIGURES 1–3 on this page provide data useful in gamma-ray shielding calculations (*1*). Included are graphs of: tenth-value thicknesses, energy at which narrow-beam absorption coefficients are a minimum, and flux equivalent to 1 r/hr.

Tenth-value thicknesses (Fig. 1) were calculated from total absorption coefficients tabulated in G. R. White's tables (*2*) using $L_{1/10} = 0.904/\mu$. (NOTE: Pb tenth-values are wrong in Fig. 4, Stanford Res. Inst. report, "Industrial uses . . . fission products" and Fig. 4, p. 57, NU, June '54.)

Energy range is that of principal interest to reactor and isotope work. For lead and tungsten the curves can be straight-line extrapolated to get values from 0.1 to 0.2 Mev, but the 0.116-Mev *K* absorption edge in uranium makes extrapolation difficult.

The thickness to attenuate by a factor other than ten can be gotten by multiplying the tenth-value thickness by the common logarithm of the desired factor; thus, half-value thicknesses are $\log_{10} 2 = 0.3010$ times tenth-value thicknesses.

The use of tenth-value layers assumes "good," narrow-beam absorption geometry; that is, that attenuation is exponential with equal attenuation in equal thicknesses. For broad-beam poor-geometry absorption, build-up of scattered radiation has to be considered (*1, 3*). However, good-geometry values are a guide and give a lower limit for transmitted intensity.

Figure 2 is based on Table 6 of ref. (*3*). Figure 3, flux equivalent to 1 r/hr, is based on the absorption coefficient of air (given in ref. (*3*), Table 10) and assumes that 1 r = 6.77×10^4 Mev/cm³ of std. air, based on 32.5 ev/ion pair.

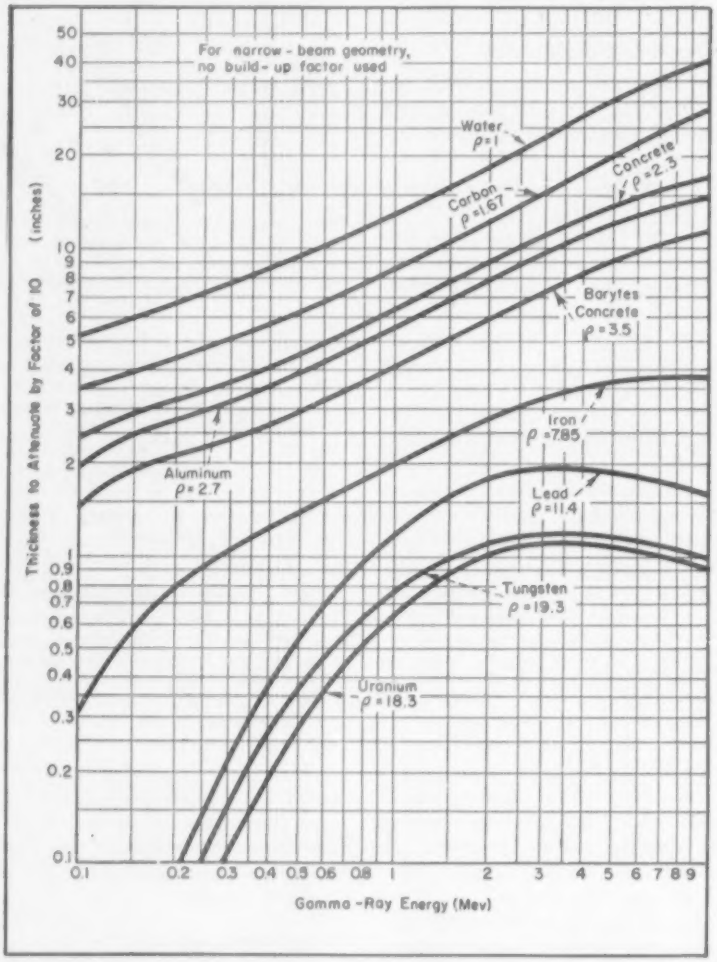

FIG. 1. Thickness to attenuate narrow beam of gamma rays by a factor of 10

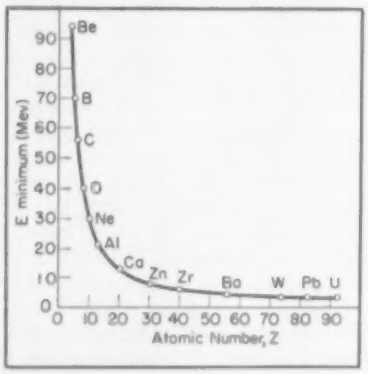

FIG. 2. Energy at which narrow-beam absorption coefficients are a minimum

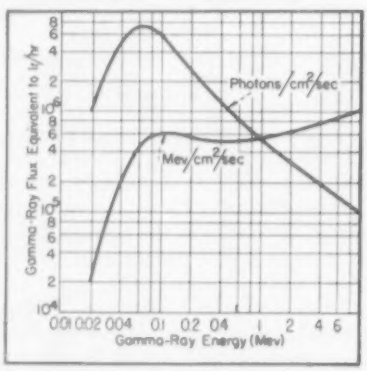

FIG. 3. Gamma-ray flux equivalent to 1 r/hr as a function of gamma-ray energy

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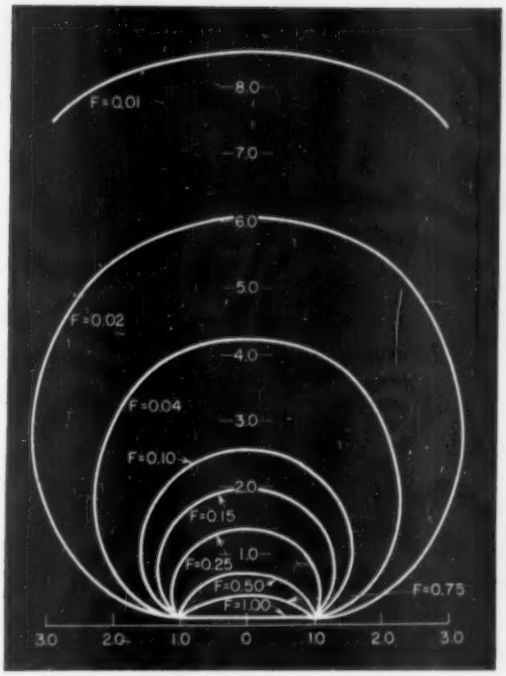

FIG. 1. Thermal-neutron isodose curves for circular opening in shield of thermal-column face normalized to unit dose at face; distance unit is radius of opening

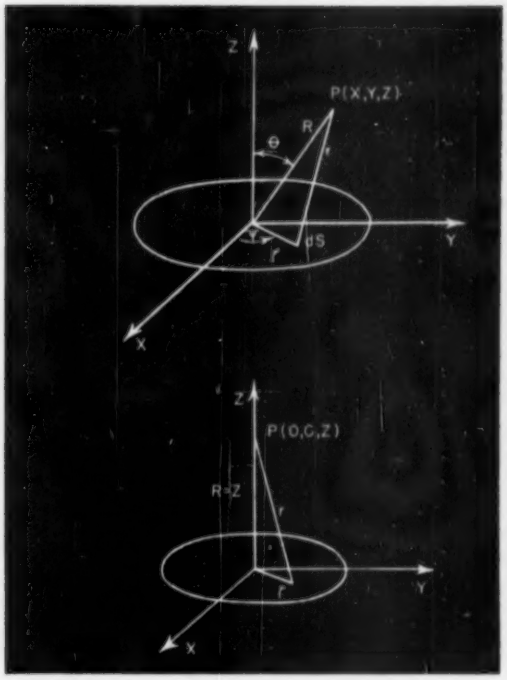

FIG. 2. Geometry for calculating neutron flux outside shield (top) at any point and (bottom) at a point on normal axis of shield opening

Neutron-Flux Distribution from a Thermal-Column Face

Efficient use of a reactor thermal column for neutron irradiation requires a knowledge of flux distribution at the column face. Thermal-neutron isodose curves are calculated on a theoretical basis for a circular opening in the shield

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North American Aviation, Inc.
Downey, California

In designing a nuclear reactor thermal column for neutron irradiation, it is important to know the flux distribution around the face, both to determine the operating power level required for a given dose rate at a specified position and to design adequately for the radiation from the column that is scattered from the walls of the room or other structures.

We calculated the isodose curves (normalized to unit dose flat against the thermal-column face) for a circular opening in the shield of a large thermal-column face (Fig. 1). Although the calculation neglects the finite thickness of the shield, this approximation is valid for any observation point from which the shield does not shadow the

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opening, and this is in general the region of major interest.

Let us assume the opening in the shield to be a circular hole of radius a. Let the plane of the shield coincide with the (x, y) plane, and let the outward normal be the direction of the positive z-axis (see Fig. 2, top).

The surface of the hole can be considered as an effective source of neutrons. We can then calculate the flux at any point P outside the shield in terms of the flux distribution in the plane of the shield.

The angular flux distribution at $z = 0$ will be denoted by $\phi(0,\mu)$, or simply by $\phi(\mu)$, where μ is the cosine of the angle between the direction in question (r) and the z-axis. Since there are no sources of neutrons in the half-space $z > 0$, the condition to be satisfied by the function ϕ is $\phi(0,\mu) = 0$, for $\mu < 0$, and it will be normalized to unit flux density

$$\int_0^1 \phi(0,\mu)d\mu = 1 \qquad (1)$$

We shall use Fermi's approximation* for the flux distribution on the interface between a pure scatterer and a vacuum

$$\phi(\mu) = \frac{1 + \sqrt{3}\mu}{1 + \frac{1}{2}\sqrt{3}} \qquad (2)$$

It has the advantage of being simple in form (linear variation with μ) without much sacrifice in accuracy. The error at $\mu = 0$ is 7.2%, but for $\mu > 0.1$ it is less than 1%.

Referring to Fig. 2, the flux at P due to an element of area $dS = \rho d\rho d\psi$ of the hole is

$$\frac{\phi(\mu)\mu}{2\pi} \cdot \frac{\rho d\rho d\psi}{r^2} \qquad (3)$$

with $\mu r = R\cos\theta$ and $r^2 = \rho^2 + R^2 - 2\rho R\cos\psi\sin\theta$. Integrated over the full area of the hole, this gives

$$F = \frac{1}{2\pi}\int_{\rho=0}^{a}\int_{\psi=0}^{2\pi} \frac{\phi(\mu)}{r^2}\,\mu\rho d\rho d\psi \qquad (4)$$

for the flux at P.

Limiting Cases

Before evaluating F for the general case, we consider special limiting cases that lend themselves to an easy solution.

1. If the point P is on the z-axis (see Fig. 2, bottom), then $\theta = 0$, $z = R$ and $\mu = R/r = R/(R^2 + \rho^2)^{1/2}$. Hence Eq. 4 reduces to

$$F = \int_{\mu_0}^{1} \phi(\mu)d\mu \qquad (5)$$

where $\mu_0 = R/(R^2 + a^2)^{1/2}$. But $\phi(\mu) = A + B\mu$, with

$$A = \frac{1}{(1 + \frac{1}{2}\sqrt{3})} = 0.537$$

$$B = \frac{\sqrt{3}}{(1 + \frac{1}{2}\sqrt{3})} = 0.926 \qquad (6)$$

Therefore

$$F = A\left[1 - \frac{R}{(R^2 + a^2)^{1/2}}\right] + \frac{B}{2}\left[\frac{a^2}{R^2 + a^2}\right] \qquad (7)$$

Table 1 shows the dependence of F and of $(1 + R^2/a^2)F$ on $R/a = \beta$ for $\theta = 0$.

It is interesting to find the limiting cases for F when either $R \ll a(\beta \to 0)$, which is equivalent to an infinite opening, or $R \gg a(\beta \to \infty)$ corresponding to a point hole. When $\theta = 0$, we use Eq 7 to obtain

$$F = A + \tfrac{1}{2}B = 1, \text{ for } R/a = 0 \qquad (8)$$

$$F \to 0.7315\, a^2/R^2, \text{ for } R/a \to \infty \qquad (9)$$

TABLE 1—Dependence of F on R/a for $\theta = 0$

R/a	F	$(1 + R^2/a^2)F$
0	1.000	1.000
0.1	0.942	0.951
0.2	0.877	0.912
0.3	0.807	0.880
0.5	0.667	0.834
0.7	0.540	0.804
1.0	0.389	0.778
1.5	0.263	0.756
2.0	0.149	0.746
5.0	0.028	0.734
∞	0	0.7315

TABLE 2—Variation of $(R^2/a^2)F$ with θ for $R/a \to \infty$

cos θ	$(R^2/a^2)F$
1.0	0.7315
0.9	0.6166
0.8	0.5112
0.7	0.4148
0.6	0.3278
0.4	0.1814
0.2	0.0722
0.0	0.0000

2. When $\theta \neq 0$, we can use the general Eq. 4 to find the limiting value of F. For $R \gg a$, we have $R \gg \rho$, $R \approx r$, and $\mu \approx \cos\psi$. Hence

$$F \approx \frac{1}{2\pi R^2}\int_0^a\int_0^{2\pi} (A + B\cos\theta)\cos\theta\rho d\rho d\psi \qquad (10)$$

which on integration gives

$$F = (a^2/2R^2)(A + B\cos\theta)\cos\theta \qquad (11)$$

i.e., $F \to 0$ for $R \gg a$.

Table 2 shows the variation of $(R^2/a^2)F$ as a function of θ for $R/a \to \infty$.

3. The case of $R \ll a$ is equivalent to letting $a \to \infty$. Hence, using this value of a as the upper limit of integration in Eq. 4

$$F = \frac{1}{\pi}\int_0^{\infty}\int_0^{\pi} \frac{A + B\mu}{r^2}\,\mu\rho d\rho d\psi$$

Then since $\mu\rho d\rho = r^2 d\mu$

$$F = \int_0^1 (A + B\mu)d\mu = 1$$

for any value of θ as long as $R \ll a$.

The General Case

In the most general case, Eq. 4 cannot be reduced to a simple readily integrable form. Inserting the Fermi approximation for the flux at the interface

$$F = A + B\mu = A + Bz/r$$

allows us to express F in terms of two double integrals, I_1 and I_2

$$F = \frac{2 - \sqrt{3}}{\pi}(I_1 + \sqrt{3}\,I_2) \qquad (12)$$

where

$$I_1 = \int_0^a\int_0^{2\pi} \frac{z}{r^3}\,\rho d\rho d\psi \qquad (13)$$

$$I_2 = \int_0^a\int_0^{2\pi} \frac{z^2}{r^4}\,\rho d\rho d\psi \qquad (14)$$

Without loss of generality, we can set up our coordinate axes in such a way as to make $y = 0$. The relationship between r and z then becomes

$$r^2 = R^2 + \rho^2 - 2\rho x\cos\psi \qquad (15)$$

with $z^2 + x^2 = R^2$, and $x = R\sin\theta$. Making use of Eq. 15, both I_1 and I_2 can be expressed in a simpler form

$$I_1 = \iint \frac{z}{r^3}\,\rho d\rho d\psi = -\frac{d}{dz}\iint \frac{\rho d\rho d\psi}{r} \qquad (16)$$

* G. Placzek, *Phys. Rev.* **72**, 556 (1947).

$$I_2 = \iint \frac{z^2}{r^4}\rho d\rho d\psi = -\frac{z}{2}\frac{d}{dz}\iint \frac{\rho d\rho d\psi}{r^2} \quad (17)$$

The integral $\iint dS/r^2$ can be evaluated without much difficulty, the integration being performed first over the azimuthal variable and then over the radial variable. The algebraic reduction is somewhat tedious but straightforward, and the final expression for I_2 becomes

$$I_2 = \frac{\pi}{2}\left(1 - \frac{\beta^2 - 1}{\sqrt{1 + 2\beta^2\cos 2\theta + \beta^4}}\right) \quad (18)$$

where $\beta \equiv R/a$.

To evaluate I_1, we use*

$$\int_0^{\pi/2} \frac{d\alpha}{(1 - k^2\sin^2\alpha)^{3/2}} = \frac{1}{1-k^2}\int_0^{\pi/2}\sqrt{1 - k^2\sin^2\alpha}\, d\alpha = [1/(1-k^2)]E(k)$$

With the substitution $\psi = 2\alpha$, we can rewrite Eq. 13 in the form

$$I_1 = 4\int_0^a \int_0^{\pi/2} \frac{z\rho d\rho d\alpha}{[(x+\rho)^2 + z^2 - 4\rho x\sin^2\alpha]^{3/2}} = 4\int_0^a \frac{z\rho E(k) d\rho}{[(x+\rho)^2 + z^2]^{3/2}(1-k^2)} \quad (19)$$

where $k^2 = 4\rho x/[(x+\rho)^2 + z^2]$. The final expression for I_1 is therefore

$$I_1 = 4\beta\cos\theta \times \int_0^1 u\sqrt{u^2 + 2u\beta\sin\theta + \beta^2} \times \frac{E\left(\sqrt{\dfrac{4u\beta\sin\theta}{u^2 + 2u\beta\sin\theta + \beta^2}}\right)}{(u^2+\beta^2)^2 - 4\mu^2\beta^2\sin^2\theta}\, du \quad (20)$$

Here we have changed our variable of integration from ρ to u, $u \equiv \rho/a$.

Unfortunately, an analytic evaluation of this last integral could not be found, and it was therefore integrated numerically for a family of values of β and cos θ.

The results of the calculation are presented in Figs. 1 and 3. The isodose contours shown in Fig. 1 have been drawn by interpolating and cross plotting in Fig. 3, and by making use of the asymptotic behaviors calculated for the limiting cases.

* W. Gröbner, N. Hofreiter, "Integraltafel," II, 221.8 (Springer-Verlag, 1949)

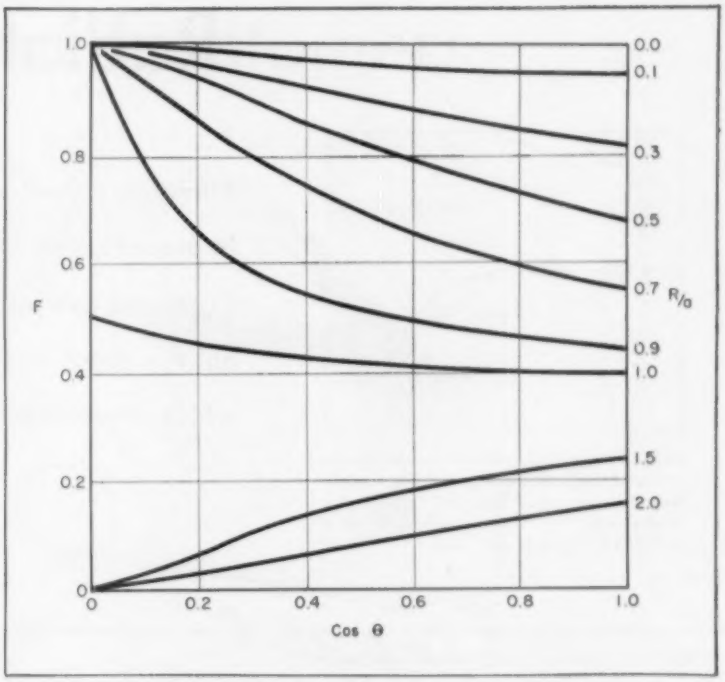

FIG. 3. Variation of F with cos θ for various values of R/a

Sample Calculation

As an example of the use of these calculations, we can consider a research reactor feeding a large graphite thermal column. The end of the thermal column is diaphragmed by cadmium and concrete to provide an 18-in.-diameter exposure port at its end.

The requirement that the thermal column has transverse dimensions large compared to the aperture of the exposure port is imposed to minimize the variation of the neutron flux over the face of the port, and hence to provide a physical situation that matches the analytical restrictions implicit in the results of this paper. If the neutron flux is not uniform across the face of the port, but falls off towards the edges (as it would in a narrow thermal column) the isoflux lobes will be narrower and extend farther from the thermal-column face than is indicated here.

We postulate that the neutron flux at the port is 10^9 n/cm²/sec. Since the unit of distance in Fig. 1 is the radius of the exposure port, or 9 in., the flux drops to 10^8 n/cm²/sec 23 in. from the face, and to 10^7 n/cm²/sec at 77 in. A tolerance dose (2,000 n/cm²/sec) is obtained directly in front of the port at a distance of 45 ft; at an angle of 60 deg to the normal of the thermal-column face, tolerance is reached at 26 ft (a normal distance of 13 ft from the thermal-column face). The exposure room would therefore be inaccessible to operating personnel during operation. Furthermore, from the curves of Fig. 1 and from the asymptotic expressions given in Table 2, we can evaluate the thermal-neutron flux incident on the walls of the room. Knowing this flux is the first step in designing adequate wall thicknesses and appropriate entrance labyrinths.

Radiation Stability

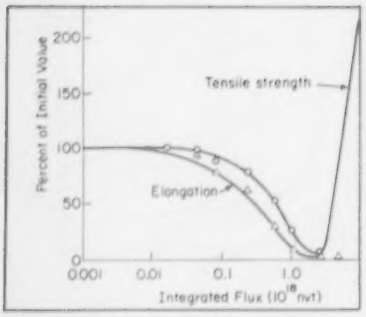

FIG. 1. Radiation affects natural rubber's tensile strength and elongation in a roughly parallel manner. This is typical for elastomers. For natural rubber, 1 nvt is equivalent to 0.6×10^{-9} rad

Although a low exposure to high-energy radiation improves certain properties of polymers, longer exposures can produce deleterious effects, as shown on the front cover. Comparison of data shows which organics best retain their properties

TABLE 1—Radiation Stability of Elastomers

Formulation	Energy absorption (rad/10^6 nvt)	Breaking elongation: Initial value (%)	Breaking elongation: Exposure for 50% decrease (10^6 rad)	Initial value of dynamic Young's modulus (10^8 dynes/cm²)
Group I—Irradiated in air-filled containers.*				
Natural rubber	0.6	420	0.5	2.3
Neoprene	2.5	450	0.06	—
Hycar OR	0.6	250	0.10	—
Butyl rubber	0.6	525	0.10	§
GR-S	0.6	270	0.10	1.8
Hycar PA	0.6	230	0.10	—
Thiokol ST	0.4	162	0.10	—
Silastic 7-170	0.7	520	0.06	—
Group II—Irradiated in helium-filled containers.†				
Polybutadiene	0.8	360	0.1	0.9
Hycar OR-15	0.8	320	0.1	1.2
Hycar OS-10	0.8	380	0.1	1.2
Neoprene GN	2.5	475	0.1	1.2
Thiokol	0.4	180	0.1	—
Silastic 250	0.7	320	0.1	4.0
Natural rubber	0.8	460	0.1	0.3
Hycar PA	0.8	660	0.05	0.6
Hypalon 82	2.5	250	0.1	3.0
Group III—Natural rubber with plasticizer.‡				
L.P. oil	0.8	560	0.1	0.33
Dioctyl phthalate	0.8	440	0.1	0.25
Dioctyl sebacate	0.8	520	0.1	0.30
Tributoxy ethyl phosphate	0.8	440	0.1	0.47
TP90B	0.8	360	0.1	—
"SC"	0.8	390	0.1	—

* Formulations are given in Table 2.

† No attempt was made to remove final traces of air from containers. These materials have different cures and different formulations than Group I, but mostly contain the same base polymers.

‡ Exact compositions are given in Ref. (*3*).

§ Durometer hardness decreases.

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DATA ON HOW RADIATION AFFECTS plastics and elastomers show a rough relationship between radiation stability and Young's modulus (*1, 2*). Generally, mineral-filled and rigid plastics are most stable, and natural rubber resists damage better than the synthetics. Addition of butyl rubber, which softens when irradiated, to natural rubber, which hardens, gives a product with irradiated strength inferior to that of natural rubber.

Elastomers

In Table 1, the pre-irradiation mechanical behavior of elastomers is characterized by the breaking elongation and the dynamic Young's modulus. Resistance to damage is shown by the exposure required to decrease elongation 50%. From the similarity in radiation effects for the groups irradiated in air or in helium, it appears that the exact amount of air present is not significant for pieces as thick as these 0.1-in. tensile specimens.

Figure 1 shows that radiation affects an elastomer's tensile strength and breaking elongation somewhat simi-

# of Plastics and Elastomers

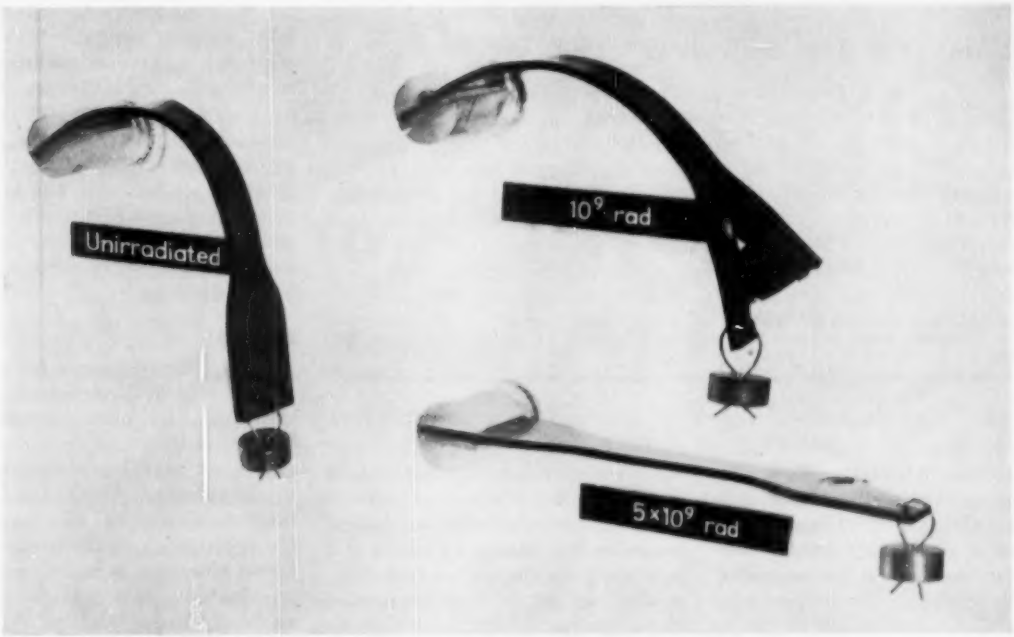

FIG. 2. Natural rubber loses elastomeric properties and becomes hard and brittle when irradiated

larly, but breaking elongation is the more sensitive. Very roughly, the exposure for 10% decreased elongation is $\frac{1}{5}$ of the 50% figure.

Natural rubber resists change best. Table 1 shows that natural rubber has fivefold better radiation-damage resistance than the other elastomers. For butyl rubber the exposure for 50% decreased elongation is of the same order as for the other elastomers, but it becomes sticky and tarry, as shown on the cover. After the same exposure, the other elastomers, which are hardened as shown by Fig. 2, may still be usable. For some purposes, natural rubber will withstand 10 times more exposure than butyl. Thiokol also becomes sticky, but at several-fold greater exposure than butyl rubber. With these exceptions, all elastomers have the same order of stability, as is indicated by the tensile test.

Straining specimen during irradiation causes greater damage. Cross-linking is predominant in elastomers that are hardened; cleavage, in those that are softened. For unstrained elastomers the net effect is given by

TABLE 2—Formulations of Group I Elastomers*

	Parts by weight						
Components	*Natural rubber*	*Neoprene W*	*Hycar OR-15*	*GR-I Butyl*	*GR-S Styrene*	*Hycar PA-21*	*Thiokol ST*
Base polymer	100	100	100	100	100	100	100
Zinc oxide	5	5	5	5	5		0.5
SRF Black	70	45	55	75	70		60
Phenyl-naphthylamine	1	2					
Stearic acid	1	0.5		2		1	3
Sulfur	3		1.5	1.5	1.75	0.5	
Captax	0.6			0.5			
Magnesium oxide		2					
Permalux		0.5					
Altax			1				
Tetramethyl thiuram disulfide				1			
Santocure					1.5		
HMF (Philblack 0)						40	
Trimene base						3	
GMF (p-quinone dioxime)							1.5
Ca-10							2
Cure: Time, min	25	20	30	60	40	60	
Temp, °F	292	307	307	307	307	310	

* Chemical formulas are given in Ref. (*2*).

TABLE 3—Percent Recovery of Elastomers Compressed 25% During Irradiation

	In jig 190 hr		*In jig 840 hr*	
*Elastomer**	*Unirradiated*	*Irradiated† 0.63 × 10¹⁸ nvt*	*Unirradiated*	*Irradiated† 0.16 × 10¹⁸ nvt*
Natural rubber	93	52	90	25
GR-S	90	53	88	22
GR-I	91	23	88	Tarry fluid
Neoprene W	62	20	42	12
Hycar OR-15	92	62	90	24
Hycar PA-21	92	58	91	14
Silastic	97	27	95	0
Thiokol ST	90	2	82	0

* Compositions are given in Table 2.
† For Neoprene, 1 nvt ~ 2.5×10^{-3} rad; for Thiokol, 1 nvt ~ 0.4×10^{-3} rad; for the others, 1 nvt ~ 0.6×10^{-3} rad.

the differences in the two processes; but if elastomers are irradiated while strained, the amount of recovery on removal of stress may be decreased both by cleavage and crosslinking. To study the loss in recovery, cylindrical specimens were placed in the jig in Fig. 3, compressed to ⅜ in., and irradiated. The recovery after removal from the jig is given in Table 3.

The loss in recovery is sizable for exposures of an order of magnitude less than are required to decrease the breaking elongation appreciably. Either of two models may be postulated to explain this. The first model pictures both cleavage and crosslinking occurring together, but cleavage effects are masked by crosslinking in the absence of strain. In the presence of strain, cleavage and crosslinking no longer tend to cancel each other, but are additive. The second model pictures the occurrence of very little cleavage, but postulates greater crosslinking effects in the presence of strain owing to the hindrance imposed upon the uncoiling of molecular segments that have become crosslinked in a strained configuration.

Evidence that the first of the two models is the more important is given by X-ray diffraction measurement of the loss in crystallinity of natural rubber irradiated to 10^7 rad while strained about 300%. The sample was protected from ozone attack during irradiation by an atmosphere of helium. The loss in crystallinity is even more sensitive to irradiation than is the loss in recovery. Since the amount of crosslinking for this low exposure is too small to affect the mechanical properties of unstrained elastomers, it is believed that the loss in crystallinity results largely from cleavage-induced stress relaxation. To further study cleavage, it is planned to measure creep during irradiation.

Adding antioxidants and mineral fillers yields no improvement. Almost all rubber formulations contain small amounts of "stabilizers" or antioxidants that protect the rubber by absorbing energy that would otherwise damage the polymer. Special formulations shown in Table 4 were made for testing the possibility that relatively large amounts of antioxidant might afford protection against radiation. Also, an attempt was made to improve the radiation stability of natural rubber by including large amounts of mineral filler in the recipe, since certain mineral-filled plastics are very resistant (*1*). No improvement in retention of either breaking elongation or breaking strength was realized for any of these formulations over the formulations of Table 2.

Compounding butyl with natural rubber gives product inferior to natural rubber. Since natural rubber is hardened by irradiation, while butyl rubber is softened, it was thought that compounding the two polymers would result in a mixture that might be more resistant than either alone. Four mixtures were tried—the recipes are given in Table 4.

The mixtures all decrease more rapidly in breaking strength and elongation than natural rubber, which is more stable than butyl rubber. But the change in hardness is less for both the 50:50 mixtures and the 25:75 mixtures than for natural rubber. This constancy in hardness is believed to result from the combined effects of cleavage, which softens butyl rubber, and crosslinking, which hardens natural rubber. For most applications the constancy in hardness will not compensate for the loss in tensile strength and elongation; thus, no net improvement over natural rubber is achieved by the mixtures.

Plastics

Table 5 lists exposures for 50% reduction of several properties. Unlike elastomers, for plastics there is no simple relation between radiation effects on breaking elongation and tensile strength. The Young's modulus of the plastics was determined from the initial slope of the tensile curve. Young's modulus is fairly sensitive to crosslinking [but it is not as sensitive as the change in solubility (*3*)], however it is often relatively insensitive to cleavage. The major effect of cleavage is to decrease breaking strength.

The order of listing the plastics in Table 5 is based approximately on the pre-irradiation value of Young's modulus. This order is significant for many applications of plastics, and it is also related to the radiation sensitivity of Young's modulus (*4*). The plastics are classified according to the range

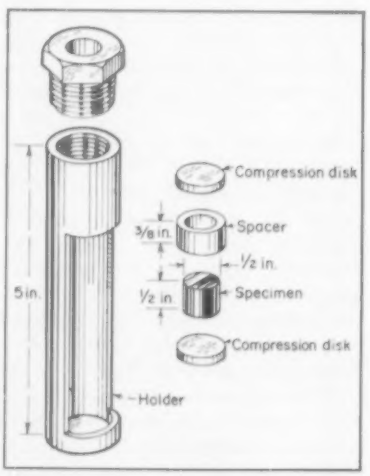

FIG. 3. Jig used to compress samples in Table 3

in which Young's modulus falls and, for composite plastics, according to the nonpolymer constituent.

Pre-irradiation properties. Group A includes plastics having high rigidity that is partly due to a large amount of mineral filler. Group B includes unfilled plastics having such high rigidity that they break with a glasslike fracture. Group C includes polymer and paper (or cloth) combinations having high rigidity. Group D includes plastics less rigid than those in Group B, but not sufficiently nonrigid to show high values of elongation in the tensile test (tensile curves of Group D plastics usually show a small amount of curvature just before the breaking point, as shown in Fig. 4). Group E includes plastics that give high elongation in the tensile test.

Post-irradiation properties. The plastics in Groups A and B show small change in either Young's modulus or breaking strength for the maximum exposure given. Often there is uncertainty as to whether an apparent change in tensile strength is real or the result of poor statistics for these rigid materials. It is planned to resolve this matter by employing greater exposures.

The paper (or cloth) phase of Group C plastics has less radiation stability than the polymer phase. Since the paper constitutes a sizable portion of the plastic, any damage to the paper weakens the plastic.

The different Group D plastics encompass a large stability range. There is little crosslinking for these moderately rigid plastics; however, the cleavage may be large or small, depending on the chemical composition (*4*).

Group E plastics, like Group D plastics, may show a large or small amount of cleavage depending on the chemical composition; however, for those in Group E the amount of crosslinking is always sizable when the amount of cleavage is small. In certain Group E plastics the change in hardness is small because of an equalization of the cleavage and the crosslinking processes; but in this case the breaking strength is decreased. For certain materials of like composition (such as vinyl chloride polymers or polyesters) the harder plastics may be predominantly cleaved; the softer plastics crosslinked.

Test Conditions

When compared on the basis of the energy absorbed, all types of high-energy radiation produce approximately similar effects on materials in which excitation and ionization are highly efficient in producing chemical reactions. To establish the validity of this observation, it is necessary to know the irradiation conditions.

Irradiation. Most of the materials were exposed in the high-flux region of the ORNL Graphite Reactor in a water-cooled (25–40° C) channel, but some irradiations were made with Co^{60} and Au^{198} sources. The maximum gamma source exposure was 10^9 rad (*5*); the maximum reactor exposure was 3×10^{10} rad.

In calculating the energy absorbed by samples in the reactor, it is generally necessary to consider fast neutrons, gammas, and secondary radiation from thermal-neutron-absorption reactions. The secondary radiation is appreciable only for elements with absorption cross sections much larger than those of either carbon or hydrogen; and it is less important for these specimens that are thin with respect to gamma absorption than it is for other geometries.

The combined high-energy radiation in the reactor amounts to about 10^6 rad/hr. The ratio of fluxes of thermal neutrons ($<\frac{1}{50}$ ev), epithermal neutrons ($\frac{1}{50}$ ev to 1 Mev), fast neutrons (>1 Mev), and gammas (assuming 1 Mev average energy), is 1.0:0.6:0.04:0.5, respectively. When the integrated flux is expressed in nvt, it means the number of thermal neutrons that have passed through 1 cm^2.

Correlation of damage and energy absorbed. Approximately equivalent changes were produced by both the reactor and gamma sources for equal energy absorption. This is not surprising since the ionization and excitation processes are similar for all types of high-energy radiation.

The term high-energy radiation is used here to include gamma and beta radiation, fast neutrons, and charged particles of all types. With fast neutrons, excitation and ionization are produced indirectly through protons ejected in collisions of fast neutrons with hydrogen atoms. The other types of high-energy radiation may cause ionization and excitation directly.

The efficiency of radiation in producing chemical reactions in materials is determined by the chemical structure of the material. Many inorganic materials are not changed greatly by gamma or beta radiation, but only by the heavier particles that produce displaced atoms. Most organic materials are changed largely by excitation and ionization. The amount of energy absorbed by ionization and excitation is generally much greater than that absorbed in displacing atoms, and often the latter may be neglected for materials damaged by ionization and excitation (*2, 6*).

The energy-absorption approximation for polymers has been tested experimentally for mechanical property changes that occur for exposures up to 10^9 rad (*2*). In the intensity range 10^4–10^7 rad/hr, agreement between gamma sources and the reactor (with

TABLE 4—Eight Specially Compounded Elastomers*

Ingredients	*Parts by weight*							
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Natural rubber	100	50	25	10	100	100		100
Neoprene W							100	
Butyl rubber		50	75	90				
Butyl reclaim					60			
Asbestos fiber	250							
Dodecyl mercaptan						10	10	
SRF black		70	70	70	70	70	40	70
Dibutyltin dilaurate								10
Calcium silicate		10	10	10				

* Complete formulations are given in Ref. (*2*).

TABLE 5—Radiation Stability of Plastics

Plastic	Energy absorption (rad/10^8 nvt)	Exposure for 50% decrease (10^8 rad)*				Young's modulus	
		Shear strength	Impact strength	Tensile strength	Elongation	Initial value (10^6 lbs/in.^{2})	Change†
A. Highly rigid mineral-polymer mixtures							
Plaskon alkyd (polyester)	0.4	>4	>4	>4	>4	32	S
Asbestos fiber phenolic	0.4	>4	>4	>4	>4	25	S
Asbestos fabric phenolic	0.4	>4	>30	>4	>4	18	S
Karbate (phenolic)	0.3	>3	>30	>3	>3	18	S
Haveg 41 (phenolic)	0.3	—	>3	>3	>3	10	S
Duralon (furan)	0.3	—	>3	>3	>3	8	S
Melmac 592 (amino)	0.4	>4	—	—	—	—	S
B. Highly rigid unfilled polymers							
Araldite, type B	0.7	>4	—	—	—	—	S
Triallyl cyanurate	0.7	>10	—	—	—	—	S
Polyvinyl carbazole	0.7	>10	>10	>10	>10	6	S
Aniline formaldehyde	0.7	10	10	10	10	6	S
C. Highly-rigid paper or linen laminates							
Paper-base phenolic	0.7	2	2	0.2	0.2	16	—
Micarta (phenolic laminate)	0.7	—	0.1	0.5	0.1	10	—
Linen-fabric phenolic	0.7	—	0.02	0.4	0.02	10	—
D. Moderately rigid polymers							
Catalin (unfilled phenolic)	0.7	1	1	1	2	6	S
Casein	1	0.4	0.1	0.4	0.4	6	S
Polystyrenes (Amphenol, Styrons 637, 671, and 411C)	0.7	>30	>30	>30	>30	5	S
Polyalphamethyl styrene	0.7	0.4	—	—	—	—	S
Lucite (methyl methacrylate)	0.7	0.1	0.1	0.05	0.05	5	S
Polyvinyl formal	1	—	—	10	10	5	D
Vinyl chloride acetate polymer	2.5	5	10	5	5	4.8	D
Cellulose nitrate	0.7	0.1	0.1	0.1	0.04	3.6	S
CR-39 (allyl diglycol carbonate polymer)	0.9	8	8	3	7	2.8	D
Pliotuf (butadiene-styrene, rubber blend)	0.8	>10	2	>10	2	2.7	S
E. Non-rigid polymers							
Styron 475 (high-impact polystyrene)	0.8	>30	0.4	>30	0.04	2.6	I
Cellulose acetate	0.7	0.2	0.07	0.2	0.07	2.6	S
Royalite (styrene copolymer)	0.8	>10	—	>10	1	2	I
Silicon-varnished glass cloth	0.6	4	—	—	—	—	I
Nylon	1	>10	0.05	>10	0.1	2	I
Ethocel (ethyl cellulose)	0.7	0.07	0.03	0.05	0.02	2.0	I
Cellulose propionate	0.7	0.04	0.04	0.04	0.04	2.0	S
Fluorothene	1	0.2	0.05	0.1	0.05	1.8	S
Cellulose acetate butyrate	0.7	0.07	0.05	0.07	0.05	1.6	S
Teflon	1	0.1	0.1	0.07	0.003	1.0	S
Mylar	1	—	—	2	1		S
Selectron 5038 (polyester)	0.8	>10	3	>10	0.1	0.6	I
Saran B-115 (vinyl chloride polymer)	2.5	1	0.5	1	0.5	0.6	S
Geon 2046 (vinyl chloride polymer)	2.5	—	—	4	0.4	0.5	S
Polyethylene	1	>10	0.5	>10	0.5	0.3	I
Butacite (polyvinyl butyral)	1	—	—	0.6	0.6	0.04	I

* For certain materials that are least sensitive to radiation, the maximum exposure given is prefixed by the symbol >.
† S = small, D = decreases, I = increases.

mixed gamma and fast-neutron radiation) was found within about a factor of two, but comparison was possible only for the more radiation-sensitive materials. Another indication of the validity of the energy-absorption approximation was obtained when plastics were irradiated in the reactor, both enclosed in cadmium and without the cadmium (*2*). The increase in the gamma flux due to the (n,γ) reaction on the cadmium was found to increase the radiation-induced change in proportion to the additional energy absorbed.

In the high-flux region of the ORNL Graphite Reactor, the energy absorption for materials composed entirely of carbon and hydrogen is given approximately by: $R = (4.8C + 0.31)N \times 10^{-9}$; where R = energy absorbed, rad; C = weight percentage of hydrogen; N = thermal neutron exposure, neutrons/cm². If elements in addition to carbon and hydrogen are present, the applicability of this relation is determined largely by the thermal-neutron-absorption cross sections and the decay schemes of the additional elements. For hydrogen and carbon the energy absorption due to thermal neutrons is small enough to be negligible. For elements with high cross sections, and especially those that do not go to stable elements, additional energy will be absorbed from the gammas and betas emitted in the absorption process and from the recoil of the atoms upon emitting radiation.

For polyethylene, the equation gives 1.0×10^{-9} rad/nvt. For the plastics and elastomers in Tables 1 and 5 that contain elements with high thermal-neutron-absorption cross sections, the rad/nvt values were obtained by comparing changes produced in the reactor with those produced in gamma sources. The tensile curve of polyethylene is extremely sensitive to the rate of straining; thus, it is not easy to compare the tensile data given here with those of other authors for different rates of straining. Also, temperature dependence has been reported for the cross-linking of polyethylene, but the effect is not large (*7*).

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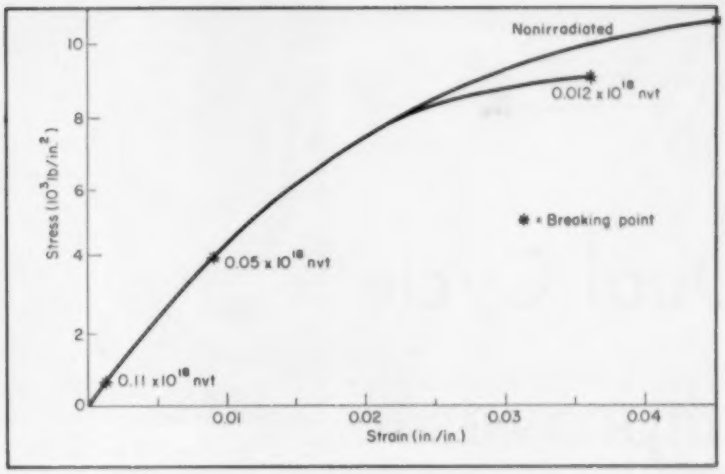

FIG. 4. Stress-strain curves for reactor-irradiated Lucite (methyl methacrylate)

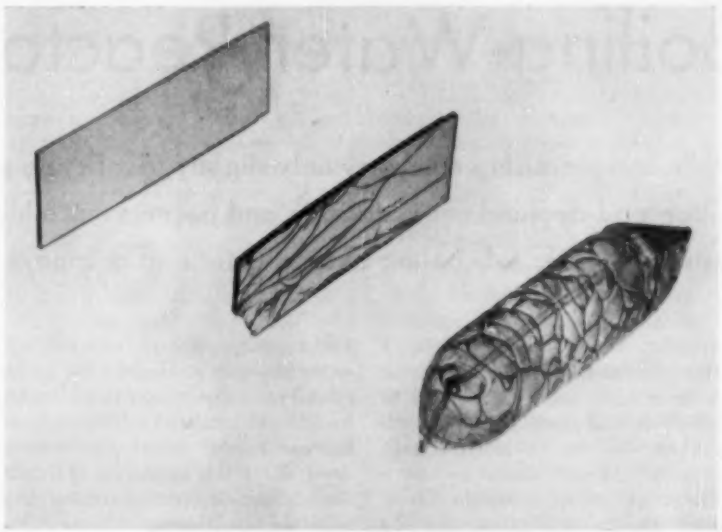

FIG. 5. Cellulose nitrate is typical of polymers that degrade by chain cleavage to become brittle and emit gas. From left to right: unirradiated, 5×10^8 rad, 10^8 rad and heated 15 min at 120°C

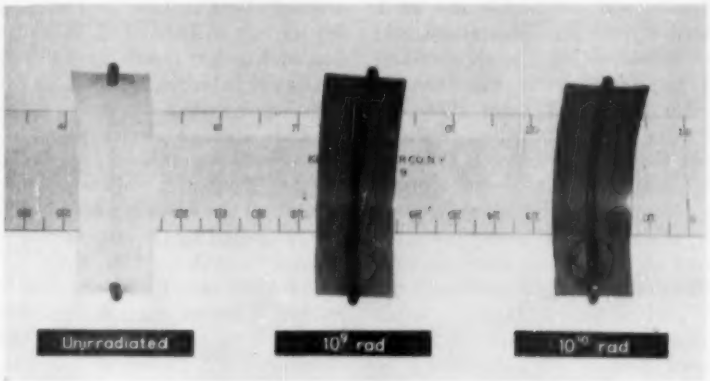

FIG. 6. Nylon is an example of a plastic that crosslinks. It first increases in strength, but with further irradiation it becomes hard and brittle. Although it darkens, it becomes more transparent due to a loss in crystallinity. Melting point increases, solubility decreases

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Dual Cycle Improves Boiling-Water Reactors

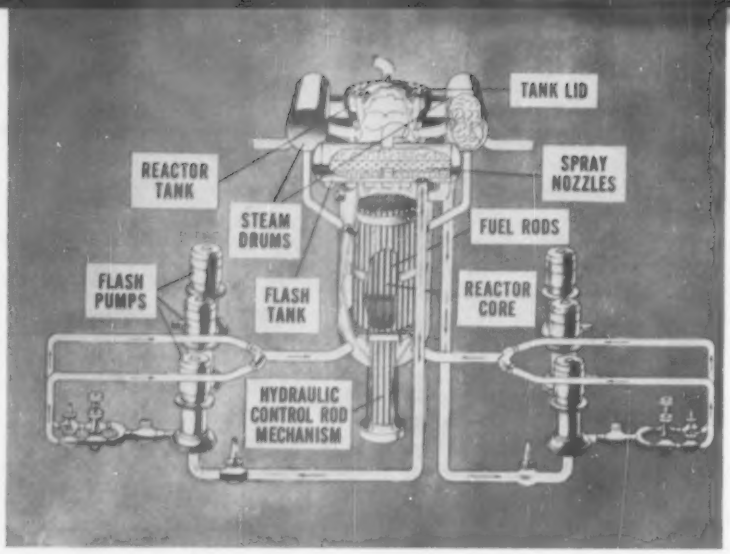


FIG. 1. Proposed 180-Mw (net) dual-cycle boiling-water reactor

While compromising efficiency only slightly, dual-cycle gives boiling reactors better load-demand characteristics and permits much higher power. A flash tank system provides subcooling of feedwater and chimneys promote natural circulation

MAXIMUM POWER and load-demand performance of a boiling-water reactor are improved by using a flash tank to subcool the feedwater. Extended cooling channels form "chimneys" that step up natural circulation.

Power output of a simple direct-boiling reactor is limited. As the moderator boils, its density fluctuates, and this affects neutron moderation and leakage. Thus, power level will fluctuate, and permissible output is limited by the maximum steam void fraction with which smooth operation can be achieved. It may not be feasible to control more than 3% reactivity with steam voids. Figure 3 shows that this corresponds to about 20% steam voids averaged through the core of a direct-boiling reactor. The relatively low power densities (about 10 kw/liter) available in large reactors under these conditions are not attractive for central station application.

Load demand characteristics of a simple boiling reactor are such that power level falls off when increased output is wanted. A sudden increased load demand increases steam flow from the reactor, pressure reduces, core water flashes to steam, and the moderation lost causes reactivity and power to fall. Control-rod adjustment can increase reactor power to meet the demand, but this takes time and makes for undesirable operation under variable-load conditions.

Mechanism of boiling. An understanding of how a simple boiling-water reactor's power output and load demand characteristics are limited by the way steam bubbles choke coolant flow and reduce reactivity will point the way to improvements possible with a dual-cycle system.

Figure 4 shows what happens in a steam-producing channel in a boiling reactor. Each of the reactor channels shown has the same steam void fraction, indicated by the same number of bubbles rising through the water.

In the first case, the water enters the reactor at boiling temperature, steam bubbles form immediately, and their concentration increases as the water rises through the channel, until the bubbles escape from the top of the reactor. All the output of the reactor is devoted to making steam.

In the next instance, the feedwater has been subcooled. One-third of the reactor's heat output raises the water temperature to the boiling point, while the remaining two-thirds generate steam. Thus, the water travels about one-third of the way through the core before boiling starts. Since the steam velocity through the reactor is the same in each case, the steam generation rate is established by the number of bubbles leaving the channel in a unit of time. Since more bubbles are formed near the top of the core in the second case, the steam generation rate is greater. Furthermore, an additional amount of heat is transmitted to subcooled water without net steam generation.

The third example shows the effect of further subcooling, so that two-thirds of the heat is used to raise the temperature of the cooling water to the boiling point. The combined heat output to produce steam and to heat water is further increased.

When the incoming water to the reactor is highly subcooled, the section of the channel that induces natural circulation becomes shorter. This suggests the possibility of promoting

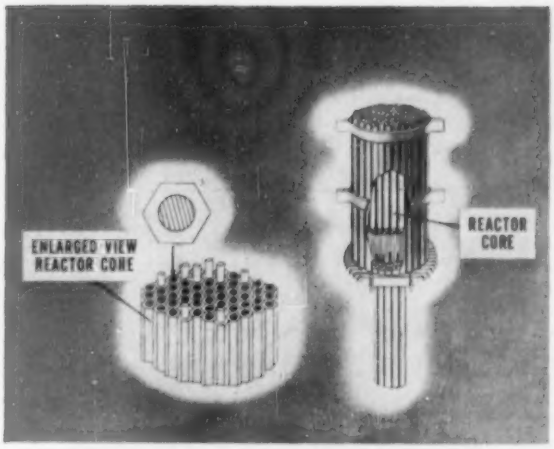


FIG. 2. Core of proposed dual-cycle boiling-water reactor. Fuel elements probably will contain partially enriched U oxide

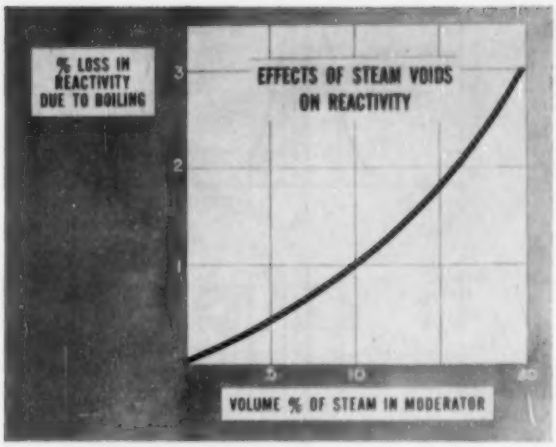


FIG. 3. Estimated effect of distributed steam voids on reactivity with core water temperature of 486° F

circulation by tubes, known as chimneys, in the water space above the fuel. The final diagram is typical of our reactor design; it shows the effect of chimneys two-thirds as high as the reactor. These chimneys augment the natural circulation lift, increasing the water velocity through the reactor. In this case, much more heat could be removed than by the system in the first diagram, if the same steam void fraction were maintained. This illustrates how the power output of a boiling reactor can be multiplied if a supply of subcooled water is available.

Dual-cycle design. The proposed dual-cycle boiling reactor shown in Figs. 1 and 2 obtains subcooled water from a flash-tank system operating in conjunction with the boiling cycle. Steam from the reactor at 600 psia and 486° F is jetted to the high-pressure stage of the turbine. The flash tank passes some of the 600-psia 486° F water from the reactor through multiple nozzles to reduce 9% to 350-psia 431° F steam, which is jetted to the low-pressure turbine. Balance of the water from the flash tank provides subcooled feedwater when mixed with water from the condenser.

None of the components incorporated in the flash cycle are large or costly, and the flash tank pumping power is only 4% of the plant output. The over-all efficiency of this cycle, with a reactor pressure of 600 psia, is about 26%, or 13,000 Btu/kwh.

As shown in Fig. 1, the reactor and associated components are assembled compactly for shielding purposes. The reactor core in Fig. 2 consists of a vertical array of slightly enriched uranium rods supported in a honeycomb of hexagonal zirconium coolant channels. Each rod is about 9 ft long.

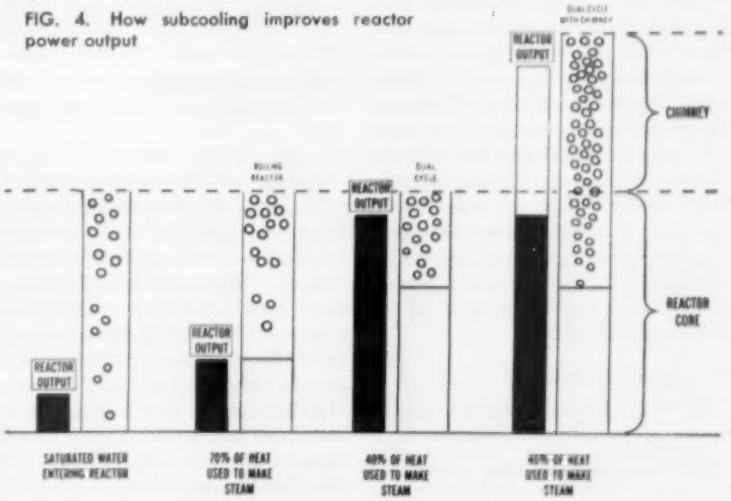
Boiling starts two-thirds of the distance above the reactor entrance. The mixture leaving the reactor contains about half steam bubbles. The weighted average of steam-bubble voids within the reactor is under 20%, corresponding to less than 2% reactivity.

Subcooling makes possible a high power output per unit volume (about 45 kw/liter). Load demand characteristics are such that power level follows demand. When more power is wanted, more steam is taken from flash tank (but flow of steam from the high-pressure line is not affected immediately) and its pressure drops, more water flows into the tank, the flash pump acts to hold the water level constant, and more subcooled water enters the reactor; this reduces steam bubbles in the core and reactor output rises to meet demand. The reactor's stainless-steel pressure vessel is 42 ft high, 12 ft i.d., and 5 in. thick.

Conclusion. The size of the largest dual-cycle boiling reactor that can be provided is limited only by the dimensions of the pressure vessel that can be transported to the construction site.

At its present stage of development, a 180-Mw (net) plant would cost about $270/kw of net output, exclusive of land costs. But the plant's simplicity and small size lead to the belief that it ultimately can be produced at a cost comparable to that of a conventional steam-generating plant (typically, about $170/kw). Thus, it appears that dual-cycle boiling reactors offer promise for competitive power.

FIG. 4. How subcooling improves reactor power output



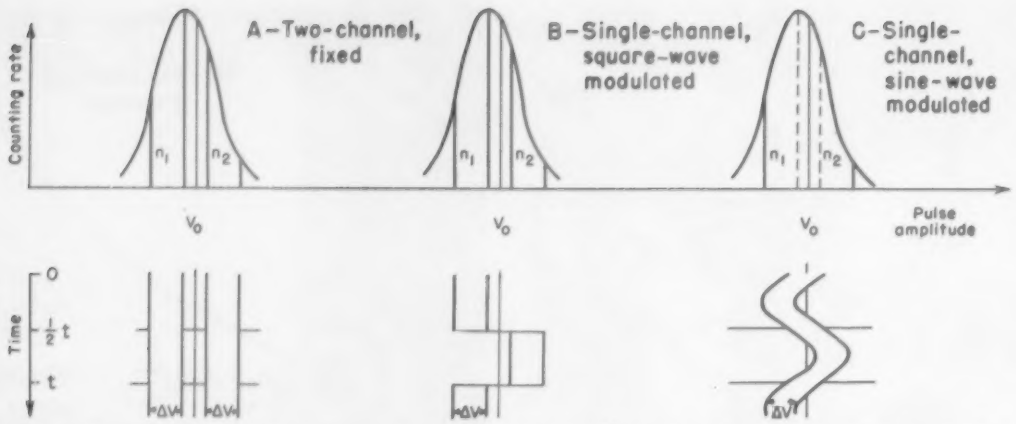


FIG. 1. Three methods of stabilization by counting-rate-difference feedback. In each case spectrum line is shown shifted to below centroid of counting channels so that lower channel gets more counts; circuit uses feedback to correct this shift

Stabilizing Scintillation Spectrometers with Counting-Rate-Difference Feedback

The stability improves by a factor of 25–55 when gain corrections are fed back to the photomultiplier voltage. Error signal is the counting-rate difference of two channels flanking a reference spectrum peak. A working stabilizer that holds for ±25% gain variations is presented, and its theory discussed

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THE RESOLUTION OBTAINABLE with scintillation spectrometers has improved greatly in the last few years, chiefly because better photomultipliers and crystals have become available. This improved performance can be fully exploited only when all parts of the spectrometer are highly stable. Despite careful construction and stabilization of the electronic units involved, difficulties may be experienced in maintaining a long-term stability better than a few per cent. Frequent time-consuming recalibrations with standard sources will often be necessary when accurate measurements of scintillation spectra must be made. The stabilization scheme presented here eliminates the need for recalibration by providing long-term feed-back stabilization based on the location of an actual spectral peak.

Sources of Instability

Any of the following effects may contribute to instability of operation:

1. Fluctuations in photomultiplier gain. This can be caused by: (a) Inconstancy of photocathode or dynode efficiency at constant interdynode voltages. (Caldwell and Turner (*1*) observed a particularly marked inconstancy of this kind for certain types of multiplier tubes that were subjected to gamma-irradiation.) (b) Changes in the distribution of voltage among the multiplier electrodes. (These may inadvertently be caused, for instance, by the signal current that runs from the last few dynodes through the voltage divider chain. This effect is generally noticeable only for rather high counting rates.) (c) Instability of total multiplier voltage.

2. Fluctuations in gain of the linear amplifier that follows the multiplier.

3. Threshold-voltage fluctuations of the discriminators in the pulse-height analyzer.

Gain fluctuations cause the distribution to shift along the pulse-height scale by an amount proportional to the

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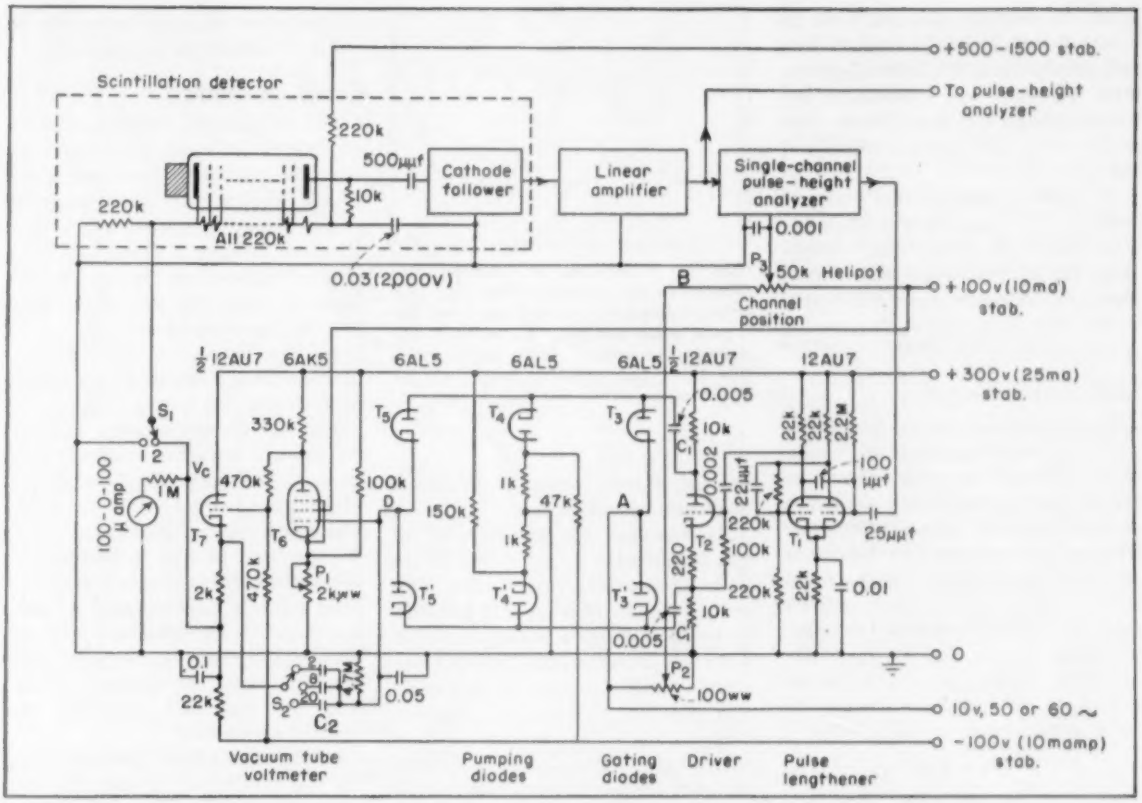

FIG. 2. Stabilization circuit employs counting-rate-difference feedback and uses sine-wave-modulated single channel

pulse height. Discriminator-threshold fluctuations chiefly cause variation of counting rate in each channel of the pulse-height analyzer.

Some tests with single-channel scintillation spectrometers showed that—at least for the instruments tested—threshold fluctuations were of relatively minor importance compared with gain fluctuations.

A stabilization method by which the influence of gain fluctuations is minimized—even though that of threshold fluctuations remains unaffected—may therefore often give a substantial improvement in over-all stability. Such a method will be dealt with in this article.

The method to be described can be applied in principle when a spectrum with at least one pronounced line is measured or also when a separate source can be used to introduce such a line into the spectrum.

Although the method can be applied to nuclear spectrometers using a proportional counter as detector, the circuit that will be given here has been developed especially for use in combination with scintillation spectrometers.

Principle of Operation

Consider a scintillation spectrum in which a pronounced line of symmetric shape occurs. Let the top of this line correspond to a pulse amplitude V_0. The counting rate in two channels of equal width, ΔV, each put on one flank of the line, will be the same ($n_1^* = n_2^*$) when the centers of these channels correspond to symmetric pulse amplitudes $V' = V_0 - V$ and $V'' = V_0 + V$. If now, for some reason, the over-all gain of the multiplier-amplifier combination changes, the line shifts. If the gain decreases, $\Delta n^* = n_1^* - n_2^*$ assumes a positive value (Fig. 1a) and if it increases Δn^* becomes negative. (Superscript * indicates a time average.)

The counting-rate difference, Δn^*, can be converted into a voltage proportional to it in a "counting-rate-difference" measuring circuit. By adding the output voltage of such a circuit to the photomultiplier voltage in the proper way, any change in the over-all amplification will be counteracted.†

The principle of counting-rate-difference feedback can also be used with only one pulse-height-analyzer channel in the stabilizing arrangement, *viz.* by switching this single channel rapidly to and fro across the top of the line. Figure 1b schematically indicates this alternative method. In this case the counting-rate-difference meter must be gated by the channel-switching voltage in such a way that pulses coming from the channel add to the charge of the reservoir capacitor of the counting-rate-difference meter when the channel is to the right of the top of the line and subtract from it when it is to the left;

† A stabilization method for proportional counters, based on a similar principle, has been previously described and analyzed by Wilkinson (2). Also, von Dardel (3) constructed a device of the same nature for use with proportional counters. In his arrangement two rotating mechanical registers, receiving pulses from two selector channels each placed on one flank of a line, are connected to the input shafts of a differential gear. The output shaft of this gear is connected to a potentiometer that controls the counter voltage.

as will be seen later, this action can be achieved rather simply. Apart from making possible some circuit simplifications, the use of only one channel has the advantage that fluctuations of its width do not influence the position of the line.

A further simplification can be realized by using a mains-frequency sinusoidal "channel-wobbling" voltage (Fig. 1c) instead of the square-wave channel-switching waveform indicated in Fig. 1b. This is the method used in the circuit to be described.

Stabilization Factor

The stabilization factor, S, is defined as the ratio between the relative shifts of the reference line with and without stabilization, caused by a certain change in over-all gain. If the multiplier voltage is denoted by V_m and its influence on multiplier gain, a, by $da/a = k\,dV_m/V_m$ and if a relative shift dV_0/V_0 of the reference line causes a change $dV_m = -\beta\,dV_0/V_0$ of the multiplier voltage as a result of the action of the stabilizer circuit, the stabilization factor can be written

$$S = 1 + k\,\beta/V_m \qquad (1)$$

If a low multiplier voltage is used, k is approximately equal to the number of multiplier stages. The factor β depends on the construction of the stabilizer circuit and can be written

$$\beta = -(dn^*/d\log V_0)(dV_m/dn^*) \qquad (2)$$

The first factor of this product gives the counting-rate difference resulting at the input of the rate meter for unit relative shift of the line. The second factor represents the sensitivity of the counting-rate-difference meter.

It is obvious that, for a certain total counting rate of this line, the first factor is twice as large for the dual-channel method (Fig. 1a) as for the step-modulated single-channel method (Fig. 1b), since in the latter case the circuit has only half the number of counts to work on. Assuming a Gaussian shape of the reference line, calculation shows further that the maximum value of the first factor of Eq. 2 for the sine-modulated single-channel method (Fig. 1c) is 0.73 times that for the step-modulated single-channel method. This maximum is obtained for a channel width of about 1.3 × and a wobbling amplitude of about 0.65 × the half-width of the reference line. This shows that the loss of stabilization resulting from the use of sine- instead of step-wave modulation is not serious.

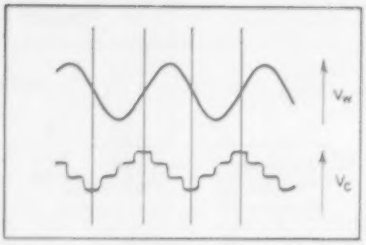

FIG. 3. Waveforms of counting-rate-difference-meter output voltage, V_C, and gating voltage, V_W, when circuit is fed 300 regular pulses per sec. V_C increases and decreases stepwise. From scope traces like these, gate-switching time could be estimated as a little less than 1 msec

As was said, the second factor of Eq. 2 represents the sensitivity of the counting-rate-difference meter. This part of the circuit consists in principle of two double-diode pumps, 1 and 2. For each incoming pulse, pump 1 can place a positive charge $+Q$ on a reservoir capacitor C; pump 2 a negative charge $-Q$. The average voltage across the capacitor, which is directly added to the multiplier voltage, can be written as $dV_m = RQdn^*$, if R is the resistance shunting C.

In the case of a sine-modulated single channel with optimum width and modulation amplitude the following formula results for the stabilization factor:

$$S \approx 0.69kn_0^*RQ/V_m\gamma_{rel} \quad \text{if } S \gg 1 \qquad (3)$$

where n_0^* is the total counting rate of the reference line and γ_{rel} its relative half-width, that is the half-width divided by the pulse height corresponding to the peak of the line.

Other factors that need to be considered in the design of a stabilizer of this type are discussed on p. 40; we will now consider the circuit itself.

Dependence of Stabilization Factor on Half-Width

Source	E_γ (*kev*)	*Relative half-width* (%)	*Stab. factor, S (approx.)*
Hg^{203}	72 (X-ray)	23	20
"	279	12	35
Co^{57}	123	14.5	30
Na^{22}	511	11	35
Cs^{137}	660	8.2	40

Circuit Description

The stabilization circuit can be incorporated in most photomultiplier arrangements simply by breaking the dynode resistor chain at its grounded side and inserting the feed-back voltage V_c there. Figure 2 shows this for a positive high-voltage supply. With a negative supply the sign of the feed-back voltage must be changed, e.g., by connecting point A in the counting-rate-difference meter to an a-c voltage of phase opposite to that at B.

The scintillation detector signal is fed through a cathode follower to a linear amplifier of conventional design. The amplified signal goes to the pulse-height analyzer intended for recording the spectrum as well as to the sine-modulated single-channel selector. Most types of single-channel selectors in current use can be adapted for the intended purpose. In the circuit given here an instrument designed by Åström (*5*) was used, in which two changes were made:

1. The channel-modulating a-c voltage was inserted at the negative side of the d-c channel-positioning voltage (point B in Fig. 2). Thus the channel-wobbling voltage is proportional to the pulse amplitude to which the selector is adjusted, and the optimum channel-wobbling amplitude is maintained irrespective of reference-line position. When this position is altered only the channel width may need readjusting.

2. The capacitor from the moving contact of P_3 to ground was reduced to 0.001 μf, making negligible the phase shift and attenuation of the channel-wobbling voltage. With other circuits care should likewise be taken lest the channel-wobbling voltage be partly short-circuited or its phase seriously shifted by excessive coupling or decoupling capacitors.

The pulse-height selector should deliver negative pulses to the counting-rate-difference meter. The first stage of this part of the circuit is a conventional univibrator acting as a pulse lengthener. It delivers pulses of 70-μsec duration and 150-volt amplitude to the driver stage T_2. Positive pulses appear at the anode of T_2, negative pulses of equal amplitude at its cathode.

Depending on the gating action of the diodes T_3 and T_3' either the posi-

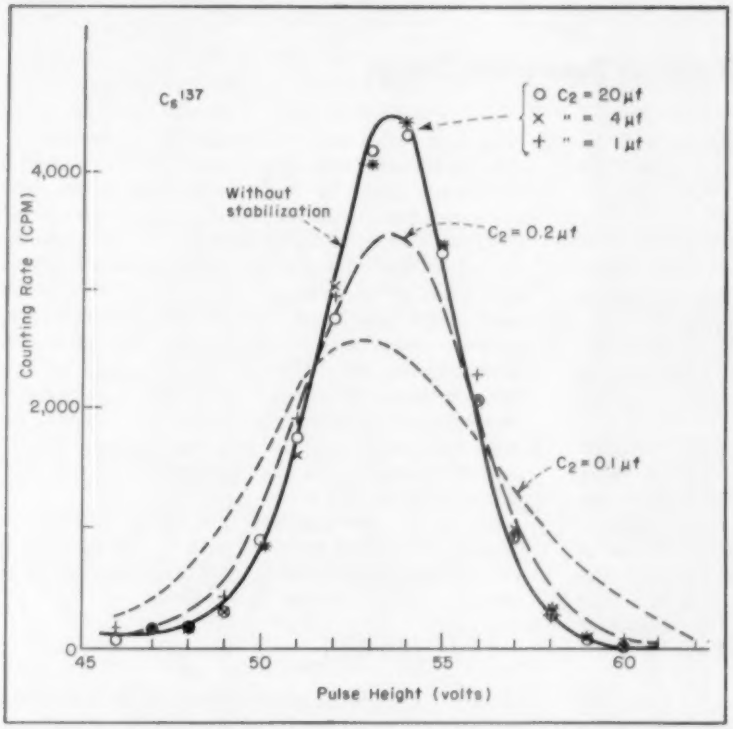

FIG. 4. Influence of reservoir capacitor C_2 (see Fig. 2) on stabilizer performance. Total counting rate of reference line was $n_0^* = 500$ cps. Solid curve gives spectrum peak without stabilization

tive or the negative pulses put the charge of pump capacitors C_1 or C_1' through diode pumps T_4,T_5 or T_4',T_5' onto the reservoir capacitor (essentially C_2). The sign of the a-c voltage at A determines which of the pumps is active. As soon as this voltage becomes a little positive, T_3 is cut off and the pump consisting of T_4 and T_5 works. T_3', however, then conducts and the cathode of T_5' becomes positive with respect to point D, isolating the reservoir capacitor from the bottom diode pump. Moreover, the negative pulses produced at the cathode of T_3' through C_1' are now more or less short circuited by T_3'.

When, after half a cycle of the gating voltage, point A becomes negative, the action is reversed and then only the bottom pump, which puts negative charge on C_2, is active.

The oscillograms in Fig. 3 illustrate the operation of the counting-rate-difference meter.

The voltage developed across C_2 is measured with a vacuum-tube voltmeter consisting of T_6 and T_7. A large part (more than 90%) of the cathode voltage of T_7 is fed back to the multiplier voltage-divider chain when S_1 is in position 2.

Operating the Stabilizer

Before a measurement is started, S_1 (Fig. 2) is set in position 1 (no stabilization) and potentiometer P_1 is adjusted without pulses entering the counting-rate meter until the counting-rate-difference microammeter reads zero. Subsequently the width and wobbling amplitude of the wobbling channel are adjusted to the optimum values $\Delta V \approx 1.3\times$ and $V_1 \approx 0.65\times$ the half-width of the reference line to be used. This adjustment is not critical.

The wobbling channel is then positioned on top of the reference line (with pulses entering the counting-rate-difference meter, of course) by bringing the microammeter reading to zero. The correct position is most quickly found by switching C_2 to its smallest value. If there are several lines in the spectrum, it may be advisable to determine first the approximate position to which the wobbling channel must be set from a preliminary measurement with the pulse-height analyzer. In such cases it may also be necessary to choose somewhat smaller than optimum values of ΔV and V_1 to avoid interference from other lines. At not-too-low counting rates only a comparatively small loss of stabilization has been observed, if, for instance, ΔV is decreased by a factor of two, while V_1 is kept constant.

Finally, the desired value of C_2 is chosen with S_2 and the stabilization circuit is activated by switching S_1 to position 2.

Circuit Performance

The following tests of the circuit were carried out:

1. Stabilization factor, S, was determined by observing the shift of the 660-kev gamma-ray line of Cs^{137} (relative half-width = 8.2%) caused by a 26% change in amplifier gain. Four different values of the total counting rate of this line, n_0^*, were used, yielding:

n_0^* (cps)	S
30	25 ± 4
100	30 ± 5
300	40 ± 6
1,000	55 ± 10

These results are not in agreement with Eq. 3, which indicates that S should be proportional to n_0^*. The discrepancy appears to be caused by the rather long switching time of the gating circuit: pulses arriving at the counting-rate meter during this time short-circuit the reservoir capacitor to some extent and therefore have the effect of reducing the resistance effectively shunting it. Since this phenomenon occurs for counting rates for which S is sufficiently large, no special effort was made to reduce its effects.

2. Influence of the half-width of the reference line on stabilization factor was determined by using different sources, each giving $n_0^* = 300$ cps. The results obtained, shown in the table on page 38, illustrate the inverse proportionality between relative half-width of the reference line and stabilization factor expected from Eq. 5.

3. Influence of statistical fluctuations of feed-back voltage on the width of a Cs^{137} gamma-ray line was studied by measuring it with different values of the reservoir capacitor C_2. The line was also measured without

Stabilizer Theory and Design

Here are more of the considerations necessary to an understanding of the feed-back stabilization scheme for scintillation spectrometers.

Statistical Fluctuations

Random fluctuations occur in the output of the counting-rate-difference meter. Since this voltage is added to the photomultiplier voltage, the multiplier gain fluctuates, resulting in random shifts of the scintillation spectrum. The influence of these fluctuations will be estimated first for the case in which the reference line itself is subjected to a measurement.

Assume that pulses with amplitudes between $U - \frac{1}{2}\Delta U$ and $U + \frac{1}{2}\Delta U$, that contribute to this line, are being accepted by the channel of the pulse-height analyzer with which the spectrum is measured. The expected standard deviation, σ, of the number of counts in this channel is composed of two parts: that resulting from fluctuations in the position of the line, σ_f, and that occurring at a fixed position of the line due to the statistical distribution of the pulses in the channel, σ_c. We may write:

$$\sigma^2 = \sigma_c^2 + \sigma_f^2 \qquad (4)$$

If a measurement takes time T and the average counting rate in the channel is n_c^* (superscript * denotes a time average), then

$$\sigma_c^2 = n_c^* T \qquad (5)$$

If the fluctuations of the line position are small compared with its half width, we may further write

$$\sigma_f^2 = (dn_c^*/d \log V_0)^2 (k/V_m)^2 \left[\left(\int_0^T V_c(t)\, dt \right)^2 \right]_{avg} \qquad (6)$$

in which $V_c(t)$ is the voltage across the reservoir capacitor. It is assumed that the stabilizing unit is adjusted so that the average value of this voltage is zero.

The first factor of Eq. 6 denotes the change of the counting rate in the pulse-height-analyzer channel per unit relative shift of the reference line. This factor is a function of the channel position U and has maxima for channel positions at both sides of the top of the line, on the steep flanks. For a Gaussian line and provided $\Delta U/U < \gamma_{rel} \ll 1$, one readily finds

$$(dn_c^*/d \log V_0)^2 \lesssim 3.8 n_0^* n_c^* \frac{\Delta U}{U} \Big/ \gamma^3_{rel} \qquad (7)$$

When calculating the value of the mean square of the integral in Eq. 6 one must realize that values of V_c at different times are statistically correlated as a result of the integrating action of the counting-rate meter, which action is defined by the effective integration time constant, τ. The influence of fluctuations in V_c on the spectrum depends on the value of τ relative to the time T in which each point of the spectrum is measured. If τ is made much longer than T and points are measured in a regular sequence along the spectrum, it is clear that parts of the spectrum measured in times of the order τ may be irregularly displaced with respect to each other as a result of the slowly fluctuating gain of the multiplier. To make such shifts sufficiently small the counting-rate-meter reservoir capacitor would have to be impracticably large and stabilization would be very slow.

It therefore seems preferable to choose an integration time constant small compared with T. In that case the calculation of the integral in Eq. 6 is quite analogous to a case discussed by Zernike (*4*) and yields

$$\left[\left(\int_0^T V_c(t)\, dt \right)^2 \right]_{avg} = [V_c^2(0)]_{avg} T\tau \qquad \text{if } \tau \ll T \qquad (8)$$

where $[V_c^2(0)]_{avg}$ is the square of the expected standard deviation for a single reading of V_c at $t = 0$. If the counting-rate meter has been on for a time much longer than τ and a total number of n_1 pulses per second enter it via both inputs this quantity becomes

$$[V_c^2(0)]_{avg} = (Q/C)^2 \int_{-\infty}^{0} [(n_1 - n_1^*)^2]_{avg} \exp(2t/\tau)\, dt = (Q/C)^2 n_1^* \tau/2 \qquad (9)$$

For optimum adjustment of width and wobbling amplitude of the sine-modulated channel one further calculates that $n_1^* \approx 0.7 n_0^*$.

The effective integration time constant is given by $\tau = RC/S$, R/S being the resistance *effectively* shunting the reservoir capacitor C. (The actual resistance R across C is reduced by a factor S as a result of the feedback action of the circuit, in very much the same way as the output impedance of an amplifier is reduced by negative voltage feedback.)

Combining the expressions just obtained with Eqs. 3, 5 and 6 one gets

$$\sigma_f^2 \lesssim (3.0 \Delta U/U\gamma_{rel})\sigma_c^2 \qquad (10)$$

This inequality has been derived under condition that the fluctuations of the line position be small compared

stabilization. It is seen from Fig. 4 that only for two very low values of C_2(0.1 and 0.2 μf) the line becomes broader, while already for $C_2 = 1$ μf the difference from the spectrum obtained without stabilization is insignificant.

For each of the three circuit tests just described, width and wobbling amplitude of the wobbling channel were adjusted to optimum values.

For a multiplier voltage of about 1,000 volts, the maximum variation of gain for which the stabilization will "hold" was found to be about $\pm 25\%$. This region may be extended somewhat by using lower multiplier voltage and higher amplifier gain.

The stabilization arrangement has been used for some time and found satisfactory for measurements of rather

with its half-width. Unless this condition is fulfilled the line will broaden. If we desire the broadening of the line to be less than a fraction $b \ll 1$ of its breadth without stabilization, we must postulate

$$(k/V_m)[(V_c^2(0)]_{av}^{1/2} < 0.6\, b\, \gamma_{rel} \qquad (11)$$

The left-hand side of this expression represents the expected standard deviation of the relative position of the top of the line. By using Eqs. 3 and 9 one can transform this relation to the condition

$$\tau > 2/bn_0^* \qquad (12)$$

The analysis has hitherto been confined to the case in which only the line used for stabilizing is measured. In general we measure a whole spectrum with a number of lines of different half-widths and intensities. Equation 11 is then certainly fulfilled for each line of the spectrum if on the right-hand side one inserts γ_{rel}^{min}, the relative half-width of the sharpest line. A simple calculation further shows that instead of Eq. 12 the condition

$$\tau > (2/bn_0^*)(\gamma_{rel}/\gamma_{rel}^{min})^2 \qquad (13)$$

must be fulfilled if the broadening of any line in the spectrum shall be less than a (small) fraction, b, of its width without stabilization. (In Eq. 13 n_0^* and γ_{rel} refer to the reference line.)

The variance of counting rate caused by the statistical character of the feedback and represented previously by Eq. 10 also depends on the choice of reference line. An extended analysis shows how Eq. 10 must be modified so as to be valid for each point of the spectrum and any reference line. Introducing a parameter $p = n_0^*/\gamma_{rel}^2$ for each line of the spectrum, calling its value for the reference line p_{ref} and its maximum value p_{max}, the estimate

$$\sigma_f^2 \lesssim (3.0\Delta U/U\gamma_{rel}^{min})\sigma_c^2(p_{max}/p_{ref}) \qquad (14)$$

is good for each point of the spectrum, showing that the line for which $p = p_{max}$ is most suitable as a reference line since it yields the lowest estimate for σ_f^2.

Operating and Design Conditions

The results of the analysis outlined in the previous section are concentrated in Eqs. 13 and 14. The right-hand side of Eq. 14 gives the maximum possible value of σ_f^2, that part of the variation of counting rate that stems from fluctuations of the feed-back voltage. This maximum is only approached when measuring on the steep flanks of the sharpest line in the spectrum. Equation 14 shows that, if the spectrum is stabilized on the line with the highest ratio of intensity to square of relative half-width, the influence of the statistical character of the feedback is determined solely by the choice of analyzer-channel width relative to the half-width of the sharpest line. Taking, for instance, $\Delta U/U = \frac{1}{2}\gamma_{rel}^{min}$ one has $\sigma_f \lesssim \sigma_c$, which means that any loss of statistical accuracy can be restored by counting at most twice as long with stabilization as without. In practice the relative channel width $\Delta U/U$ is usually kept smaller for accurate measurement so that σ_f will in general be smaller. It may be inadvisable to use the line with $p = p_{max}$ as the reference line if that line is poorly resolved or has a strong background. A glance at the spectrum, however, usually reveals a suitable line with a not much smaller value of p.

From these arguments it may be concluded that *in many cases no serious loss of statistical accuracy will result by following the same measuring procedure with stabilization as without. If wide analyzer channels or a weak or broad reference line must be used, at least the same statistical accuracy is achieved for each point of the spectrum by increasing the measuring times by a factor*

$$1 + (3\Delta U/U\gamma_{rel}^{min})p_{max}/p_{ref}$$

Equation 13 offers estimates for some circuit parameters after the maximum allowable broadening of the sharpest line has been specified. Suppose we, conservatively, wish to keep this broadening smaller than 2% of the width without stabilization ($b = 0.02$). To achieve then a stabilization factor $S = 20$ at a total reference-line counting rate $n_0^* = 100$ cps, we must for instance make $RC = \tau S > 20(\gamma_{rel}/\gamma_{rel}^{min})^2$. Assuming, perhaps somewhat arbitrarily, that the half-width of the reference line will not be more than twice that of the sharpest line, we find that RC must be longer than 80 sec.

A further circuit condition may be derived from the formula for the stabilization factor (Eq. 3) by inserting in it some values met in common practice, such as $V_m = 1{,}000$ volts, $k = 10$ and $\gamma_{rel} = 0.1$. Equation 3 then reduces to $S \approx 0.07 n_0^* RQ$. With a demand for $S = 20$ at $n_0^* = 100$ cps this requires $RQ \approx 3$ volt sec. If the driver stage of the counting-rate meter delivers pulses with an amplitude of 100 volts through pump capacitors C_1, this requirement implies $C_1 = Q/U_1 = 0.03/R$. Combining with the estimate for RC we see that we must make $C_1 < 4 \times 10^{-4}\, C$. In the circuit described $C_1 = 5{,}000$ $\mu\mu$f, $R = 4.7$ Meg and reservoir capacitors of 2, 8 or 20 μf are used.

complicated spectra. As remarked before, an extra line may be inserted if the spectrum to be investigated shows no peak of sufficient quality to be used as a stabilizer. An elegant manner of creating such a line consists of placing beside the gamma-detecting crystal a small NaI(Tl) crystal irradiated by a source of monoenergetic alpha particles.

* * *

The author is much indebted to Professor Manne Siegbahn for extending to him the hospitality of the Nobel Institute of Physics. A stipend of the Netherlands Organization for Pure Research (Z.W.O.) is gratefully acknowledged.

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CROSS SECTIONS

Cobalt-60 Field Irradiation Machine

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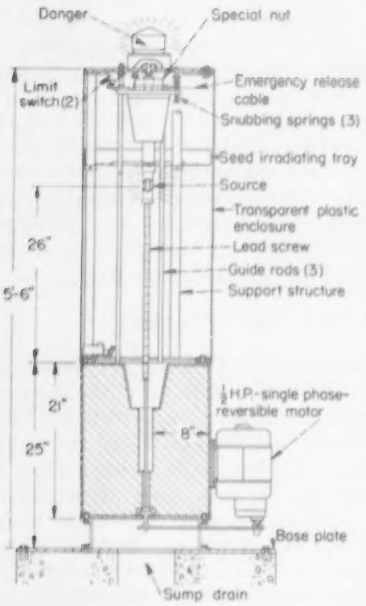

COBALT-60 IRRADIATION UNIT with source in irradiating position. Nut fastened to top of plug enables plug and source assembly to rise to irradiating position; microswitches at upper support plate open motor circuit and energize two red lights, one at remote control station and other on top of upper plate when source is in position; switches on top of container perform similar function when assembly is returned to container. Emergency-release cable causes specially designed nut to open into two halves, permitting source and plug to drop into container; snubbing springs dampen shock of fall; slight design change could provide for automatic fail-safe system. Base plate is bolted to concrete foundation or floor of trailer. Provision should be made for rainwater drainage; plastic or aluminum blister covering upper section prevents collection of water or debris. It requires about 30 sec for motor to drive assembly into position. Seeds or materials requiring high radiation dose can be exposed in aluminum tray attached to source supports; dose rate is approximately 5,000 r/hr

In the Brookhaven Laboratory Co^{60} radiation field (*1*), utilizing a 1,600-curie source, it has been possible to produce abundant endosperm mutations in growing corn plants and to calculate a dose-response curve for such mutations (*2*, *3*). However, it has been shown recently (*4*) that, with a radiation dose of 1,300 r, one-day exposures produce maize endosperm mutations at the rate of about 3% per gene if given at the most sensitive period, i.e., about a week prior to pollen shedding.

The doses required can be obtained by placing the plants fairly close to the source. The machine proposed here accomplishes this by permitting either the plants or the machine to be portable.

Description of Machine

The design of the source, shield, and auxiliary equipment described here is proposed primarily for field installation. The lead container or shield safely houses a 200-curie Co^{60} source. In working up the auxiliary equipment, efforts have been concentrated on making the package as complete as possible to keep to a minimum the amount of preparation necessary for installation at any site.

The source material weighs 250 gm, and is fashioned in the form of a tube, of $\frac{1}{8}$-in. wall thickness, 4-in. length and 1.1-in. o.d. This cobalt tube is placed between two concentric aluminum tubes, the ends of which are welded. The assembly is first tested for leaks and then anodized. The finished source encased in aluminum is $4\frac{1}{8}$ in. long, $1\frac{1}{4}$ in. o.d., and $\frac{3}{4}$ in. i.d. The entire assembly is then irradiated in the reactor. A 200-curie source of this type would require about six months' irradiation in the BNL reactor.

The lead shield weighs about 1 ton. A 200-curie source, together with container and auxiliary equipment, would cost less than $5,000.

Approximate Doses from 200-Curie Source

Distance (meters)	*Radiation dose rate*	
	r/hr	*r/24-hr day*
1.5	122	2,928
2	70	1,680
3	30	720
4	17	408
5	11	264
6	7.3	175
7	5.2	125
8	4.1	98
10	2.6	62
14	1.3	31
20	0.64	15
28	0.32	7.7
40	0.15	3.6
57	0.074	1.8
80	0.036	0.9

An approximation of the radiation levels at different distances from the source is given in the table, based upon measurements made on a 1952 radiation field using Victoreen Co^{60} chambers. These values assume an on-grade installation. Measurements were made out to 20 meters and calculated according to the inverse-square relationship from there on. The values for 200 curies given in the table are 76% of those measured for the 1952 262-curie source. Based on previous experience, it is evident that the rows out to 3 meters would be the most effective in producing mutations by exposing plants for one day only. The actual values for any installation will have to be measured since any source delivered will not be exactly 200 curies.

* * *

We wish to thank Mr. A. Oltman who helped materially in the design of the machine described here and also in preparing the drawing. This work was done under the auspices of the U. S. Atomic Energy Commission.

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Alpha-Particle Autoradiography with Liquid Emulsion

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The problem of track and particle registration, encountered with nuclear emulsion plates, is avoided by liquid emulsions (*1*, *2*) that are not removed from the radioactive specimen throughout the autoradiographic process. Although thin sections of rock were the subject of the present study, the method should be applicable in alpha-particle autoradiography of many different types, e.g., histology and botany.

Procedure

The following procedure was developed during a study of Wisconsin granites and related rocks (*3*).

1. Thin sections are made of the rock specimen by the standard method, except that the cover glass and its cement are omitted. The excess cement holding the thin section to the microscope slide is scraped off, and debris from grinding is removed by washing with ethanol.

2. After attaining radioactive equilibrium with respect to radon (approximately one month), the thin section is dipped in the emulsion binder solution and dried in a horizontal position.

3. When the emulsion binder is firm, Kodak NTA bulk emulsion, heated to fluidity in a 45° C water bath, is applied as uniformly as possible to the binder-coated top of the thin section. Darkroom conditions must be maintained, as Kodak NTA emulsion is light-sensitive. A medicine dropper is used to apply the emulsion, thickness (50–75 microns) being readily controlled with a little practice.

4. The emulsion layer is dried in an air stream. The loaded specimen is then stored at 5° C in a light-tight box. Exposure time depends upon the alpha-particle flux and the particular problem. With Wisconsin granites, 20 days gave an adequate density of alpha-particle tracks.

5. At the end of the exposure period, the emulsion is developed. The development process is: (a) 15 min presoak in 3% chrome-alum hardening solution at room temperature; (b) rinse in distilled water; (c) develop 2 min in Kodak D-8 at 18° C; (d) stop bath—1 min in distilled-water wash at 0° C or 1 min in 3% acetic acid solution at room temperature; (e) 5 min in prefixer hardener at room temperature; (f) fix—twice time to clear in Kodak Rapid Fixer plus Hardener (F-5 is satisfactory, but slower); (g) wash—60 min in running tapwater; (h) dry developed emulsions in a horizontal position to prevent slumping of the softened emulsion and consequent rupture of alpha tracks.

6. When the emulsion is completely dried, the specimen is examined with a petrographic microscope. By focusing on the thin section, the mineral grains can be identified by conventional methods. By focusing on the emulsion above the thin section, alpha-particle tracks can be studied at 210 or 450 magnifications with regard to density and mineral of origin.

PHOTOMICROGRAPH-AUTORADIOGRAPH showing alpha-active allanite as core material to pleochroic halo in biotite (magnification: 250×; plane-polarized light); three dark portions of biotite surrounding alpha-emissive allanite are optically continuous

Autoradiographic Materials

Experimental liquid Kodak NTA Emulsion stored at 5° C

Emulsion binder: dissolve 25 gm of soft gelatin in 250 ml of distilled water at about 60° C; allow it to stand for ½ hr; filter off the unhydrated gelatin; add 2.5 ml of 5% chrome alum and 10 ml of 0.2% wetting agent (Aerosol)

Hardening solution: 3.0% chrome alum in distilled water

Kodak D-8 developer

Prefixer hardening solution: 15 gm chrome alum and 30 gm anhydrous sodium sulfate in 1,000 ml of distilled water

Kodak Rapid Fixer with hardener or Kodak F-5 Fixer

Darkroom conditions: Wratten Series OA filter over 7½-watt safelight

Discussion

This procedure produced highly satisfactory autoradiographs (see illustration).

At 450 magnifications it is impossible to detect the emulsion-binder thickness. Curling and peeling of emulsion from the thin section were noted when emulsion binder was not used. Peeling of the emulsion and thin section from the microscope slide occurred when the thin section was not firmly cemented to the microscope slide. After one year, emulsions showed no sign of deterioration.

Background was determined by carrying blank microscope slides through the autoradiographic procedure. Background was about 5 alpha-particle tracks per square centimeter of developed emulsion. The background tracks were produced predominately from alpha-emitting nuclides in the emulsion itself.

Even when stored at 5° C, the bulk emulsion, air-expressed from Eastman Kodak Company immediately after preparation, did not remain in useable condition indefinitely. After a month or so, it separated.

* * *

The authors would like to thank the Eastman Kodak Company, especially W. F. Swann, for supplying the experimental Kodak NTA bulk emulsion gratis and arranging for its quick delivery. This research was supported by AEC research contract AT(11-1)-178.

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Radioactive-Source Corrections for Bremsstrahlung and Scatter

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The primary gamma radiation from radioactive sources is always accompanied by secondary X- and γ-radiations consisting of bremsstrahlung and scatter. These secondary radiations are usually neglected on account of their low intensity relative to that of the primary radiation. However, in cases where it is necessary to correct for the effect of bremsstrahlung and scatter, both the intensity and the spectral distribution are required. This information can be obtained from the formulae and tables presented here with an estimated accuracy of 20%.

Bremsstrahlung

The discussion of bremsstrahlung intensity and spectral distribution must consider beta rays and monoenergetic electrons (internal-conversion electrons).

Intensity. The intensity of bremsstrahlung can be calculated from the theory given by Heitler (*1*). For a beta emitter, the energy radiated as bremsstrahlung, measured in Mev per beta ray, is (*2*)

$$B = 1.23 \times 10^{-4}(\bar{Z} + 3)E_\beta^2 \quad (1)$$

where E_β is the maximum kinetic energy (Mev) with which beta particles are emitted, and $\bar{Z}$ is the effective atomic number of the material in which the beta particles are brought to rest, as defined by

$$\bar{Z} = \Sigma\alpha Z_a^2/\Sigma\alpha Z_a \quad (2)$$

where α is the fraction of the total number of atoms having the atomic number Z_a (*2*). The numerical term 3 in the bracket of Eq. 1 accounts for the internal bremsstrahlung. Equation 1 applies strictly to isotopes whose β-ray spectra have the same shape as that of P^{32}, but the variations for other isotopes may be ignored for the present purposes. A correction to Eq. 1 should be made if an appreciable fraction of β-rays escape from the source; this may be calculated from a modification of formulae given by Richards and Rubin (*3*). A correction may also be necessary for absorption of bremsstrahlung by the source material.

The energy of bremsstrahlung produced by monoenergetic electrons, such as internal-conversion electrons, is similarly calculated as

$$C = 5.77 \times 10^{-4}\bar{Z}E_e^2 \quad (3)$$

where E_e is the initial kinetic energy of the electron (*2*).

The effect of the bremsstrahlung upon any measurement depends on the ratio of the rate of emission of bremsstrahlung energy to the rate of emission of γ-ray energy. If, for a particular isotope, a fraction β of the disintegrations results in the emission of beta rays with maximum energy E_β and a fraction γ results in the emission of gamma rays of energy E_γ, then, summing for all beta and gamma rays, the ratio of the intensity of bremsstrahlung to the intensity of the primary gamma radiation is

$$\frac{B}{P} = \frac{1.23 \times 10^{-4}(\bar{Z} + 3)\Sigma\beta E_\beta^2}{\Sigma\gamma E_\gamma} \quad (4)$$

Equation 4 may require correction for bremsstrahlung from internal-conversion electrons (usually very small), for loss of beta rays and electrons from the source, and for absorption in the source. At present, the biggest error in applying Eq. 4 usually arises from incomplete knowledge of the decay scheme.

Spectral distribution. The spectral distributions of bremsstrahlung from beta rays and from monoenergetic electrons have been calculated by Wyard (*4*). Bremsstrahlung are emitted with all energies from zero up to the maximum energy of the beta rays (E_β) or the electrons (E_e).

If the spectrum is divided into ten equal energy intervals, then the percentage of the total intensity that is emitted in each interval is given in Table 1. Table 1 has been checked experimentally for bremsstrahlung from P^{32} (*5*), and agreement was within 10%. The bremsstrahlung spectrum given in Table 1 applies strictly only to isotopes whose beta-ray spectra have the same shape as that of P^{32}, but variations for other isotopes and also for internal bremsstrahlung may be ignored for the present purposes.

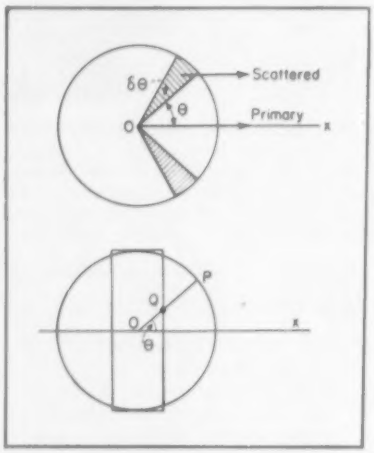

FIG. 1. Geometry of radiation scattered from (top) sphere and (bottom) cylinder

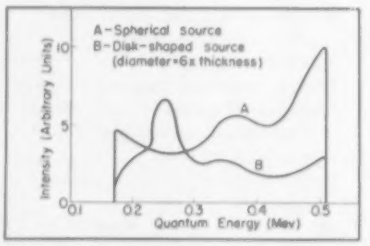

FIG. 2. Intensity distribution of scatter from radioisotope emitting 0.51-Mev γ-rays

Scatter

The following discussion treats the intensity and spectral distribution of scatter for spherical and cylindrical sources.

Intensity. For a point source of γ-radiation situated at the center of a sphere, the ratio of the intensities of the scattered and the primary radiations is, to a first approximation

$$S/P = r\sigma_s = r\rho(NZ/A)_a\sigma_a \quad (5)$$

where r and ρ are the radius and density of the sphere, and σ_s and $_a\sigma_a$ are the Compton scatter coefficients. In Eq. 5, it is assumed that the absorption of the primary radiation by the material of the sphere is not very great; also the difference of absorption between the primary and scattered radiations is neglected. If the radioactive material is spread uniformly throughout the sphere, then the scatter is 25% less than the value given by Eq. 5 because of the reduced average path length of the primary radiation in the sphere.

Spectral distribution. The spectral

distribution of the scattered radiation from a sphere can be calculated by dividing the sphere into a series of cones of semiangle θ (Fig. 1). All the radiation that is scattered by the shaded portion in Fig. 1 (top) in the direction Ox has the same quantum energy

$$\lambda_s = \lambda_0 + 24.3(1 - \cos\theta) \quad (6)$$
$$E = 12.4/\lambda \quad (7)$$

The intensity of the scattered radiation with this quantum energy is proportional to $K_\theta \sin\theta$, where K_θ is the fraction of γ-radiation scattered per electron per unit solid angle in the direction θ. Values of $(\pi^2/90)K_\theta \sin\theta$ have been calculated by Tarrant (*6*, Table 2).

For a source in the shape of a cylinder, the intensity and the spectral distribution of the scattered radiation that proceeds in the direction of the axis of the cylinder can be calculated from the spectral distribution for a sphere. The intensity of radiation scattered at an angle θ is obtained by multiplying the value calculated for a sphere by the ratio OQ/OP (Fig. 1, bottom); the total intensity is obtained by summation over all values of θ.

As an illustration we consider a source with quantum energy 0.51 Mev. For a sphere of mass 5 gm composed of material of unit density and low or medium atomic number, the relative intensity of scatter is given by Eq. 5 as 5.5%. If the difference in absorption between the primary and scattered radiations is taken into account, this figure is reduced to 5.2%. If the radioactive material is spread uniformly throughout the sphere, the figure is further reduced to 3.9%. The spectral distribution of the scattered radiation is given by curve *A* of Fig. 2. If the same quantity of material is spread into a disk whose diameter is 6 times its thickness, then the intensity of scatter in the direction of the axis of the disk is little over half that for the sphere; and the spectral distribution is given by curve *B* of Fig. 2.

Applications

Corrections for bremsstrahlung and scatter are particularly important in two situations: firstly when radioactive isotopes are used as sources of monochromatic radiation, and secondly in gamma-ray dosimetry. Table 2 gives the ratios of bremsstrahlung intensity to primary γ-ray intensity for isotopes commonly used for these purposes.

The calculated values in Table 2 were obtained directly from Eqs. 3 and 4. The measured values were obtained from absorption experiments that give the intensity ratios directly and independently of the strength of the source. The measured values have been corrected for loss of beta rays from the sources used, and for absorption of bremsstrahlung within the sources.

TABLE 1—Spectral Distribution of Bremsstrahlung

Energy range (fraction of E_β or E_0)	*Percentage of total intensity*	
	Beta-ray spectrum	*Electron spectrum*
0–0.1	43.5	26.9
–0.2	25.8	20.5
–0.3	15.2	15.8
–0.4	8.3	12.1
–0.5	4.3	9.0
–0.6	2.0	6.5
–0.7	0.7	4.5
–0.8	0.2	2.8
–0.9	0.03	1.5
–1.0	0.00	0.4

In gamma-ray dosimetry, the correction for scatter is usually combined with the correction for absorption of the primary radiation in the source (*7*); but it is sometimes instructive to calculate the effects separately.

The dose rate from radium is of particular importance in gamma-ray dosimetry. The standard source is specified as having a filter of 0.5-mm platinum, but this specification does not give a definite dose rate, since the intensities of bremsstrahlung and scatter depend on the shape, size, and composition of the source and on the shape and size of the platinum container.

We shall therefore calculate the contributions to dose rate from bremsstrahlung and scatter for an ideal source consisting of a radium point source at the center of a 0.5-mm-radius platinum sphere. Applying the formulae given previously and making a small correction for the variation of the true absorption coefficient of air with quantum energy, we find that the ratio of dose rate due to scatter to dose rate due to primary gamma radiation is 2.8%. The dose rate due to primary radiation is reduced by a factor of 0.892 by absorption in 0.5-mm platinum, so the combined effect of scatter and absorption, i.e., the effective absorption, is to reduce the dose rate by a factor of 0.915. The dose rate due to bremsstrahlung is found to be 1.5% of the dose rate due to the primary radiation, so that the final correction factor to be applied to the value for the dose rate calculated for an unscreened source is 0.928.

In a practical radium tube with 0.5-mm-platinum filtration, the dose rate from bremsstrahlung will be less, because some of the bremsstrahlung is produced in material whose atomic number is lower than that of platinum. However, the scatter dose rate will be more, because there is a greater mass of platinum than in the ideal source.

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TABLE 2—Ratio of Bremsstrahlung to Gamma Ray-Intensity

Isotope	*No. of γ-rays per disintegration*	*Bremsstrahlung from solid sources*			*Bremsstrahlung from dilute aqueous solutions, calculated intensity (%)*
		Chemical form of source	*Calculated intensity (%)*	*Measured intensity (%)*	
Co^{60}	2	Co	0.01	0 ± 1	0.005
Ru^{103}	0.99	RuO_2	0.06	0 ± 1	0.01
Hg^{203}	0.77	HgO	0.4	0 ± 5	0.04
K^{42}	0.15	K_2CO_3	10.6	10.5 ± 2	7.3
Rb^{86}	0.084	RbCl	13.5	13.4 ± 2	3.8
Tm^{170}	0.003	Tm_2O_3	310	Not measured	47

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Millicurie β-Ray Point Source

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A β-ray source of less than 0.04-in. diameter was successfully made by the following procedure.

A circular disk, somewhat less than 1-in. diameter, was cut from 0.04-in.-thick Lucite sheet, which stops most of the weak Sr^{90} β-rays and permits Y^{90} betas to penetrate. A lip cut in the disk and bent up permits easy handling.

A small glass bead on the end of a capillary tube was heated sufficiently to soften Lucite but not to melt it. With the aid of a magnifying glass, a depression of less than 0.04-in. diameter was made at the center of the disk with the warm bead.

The disk was then placed in a Lucite support covered with masking tape to facilitate decontamination. A piece of cellophane tape was pasted onto the disk (see Fig. 1).

This assembly was put in a gloved box. A syringe with hypodermic needle was carefully filled with an undiluted solution of Sr^{90} from Oak Ridge (12 mc/ml) and mounted obliquely on a small stand inside the box. The flat portion of the needle tip pointed down.

A small drop of highly radioactive solution was now formed on the tip of the hypodermic needle. The disk-holder assembly was then carefully raised from below toward the needle point (Fig. 1) so that contact was made only between the drop and the central dip of the Lucite disk. On lowering the holder assembly, the radioactive droplet appeared as a small spherical bead in the central depression of the disk. On complete evaporation, the radioactive material was confined to the inside of the central depression.

When very strong sources were required, the procedure was repeated several times. Care had to be taken, however, that before a new droplet was placed in the dip, the preceding one had completely evaporated to dryness.

With the aid of an uncontaminated piece of paper, the cellophane tape was firmly pressed over the source depression.

The disk assembly was now removed from the gloved box, and the disk taken out of the holder. Smear tests of the disk proved negative. In this manner, several sources up to 2-mc strength were prepared.

A collimator providing a pencil of parallel β-rays with these sources is shown in Fig. 2.

* * *

This work was supported in part by the U. S. Atomic Energy Commission.

FIG. 1. Placing radioactive drop, suspended from tip of hypodermic needle, in depression in center of Lucite source disk; operation is performed in gloved box

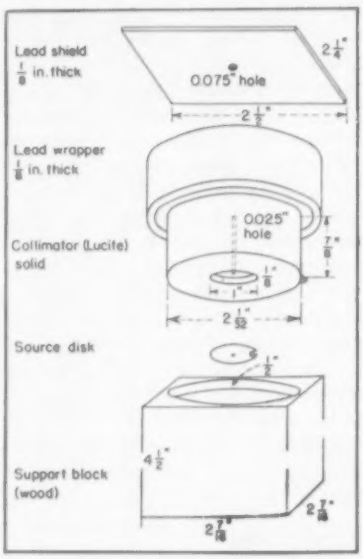
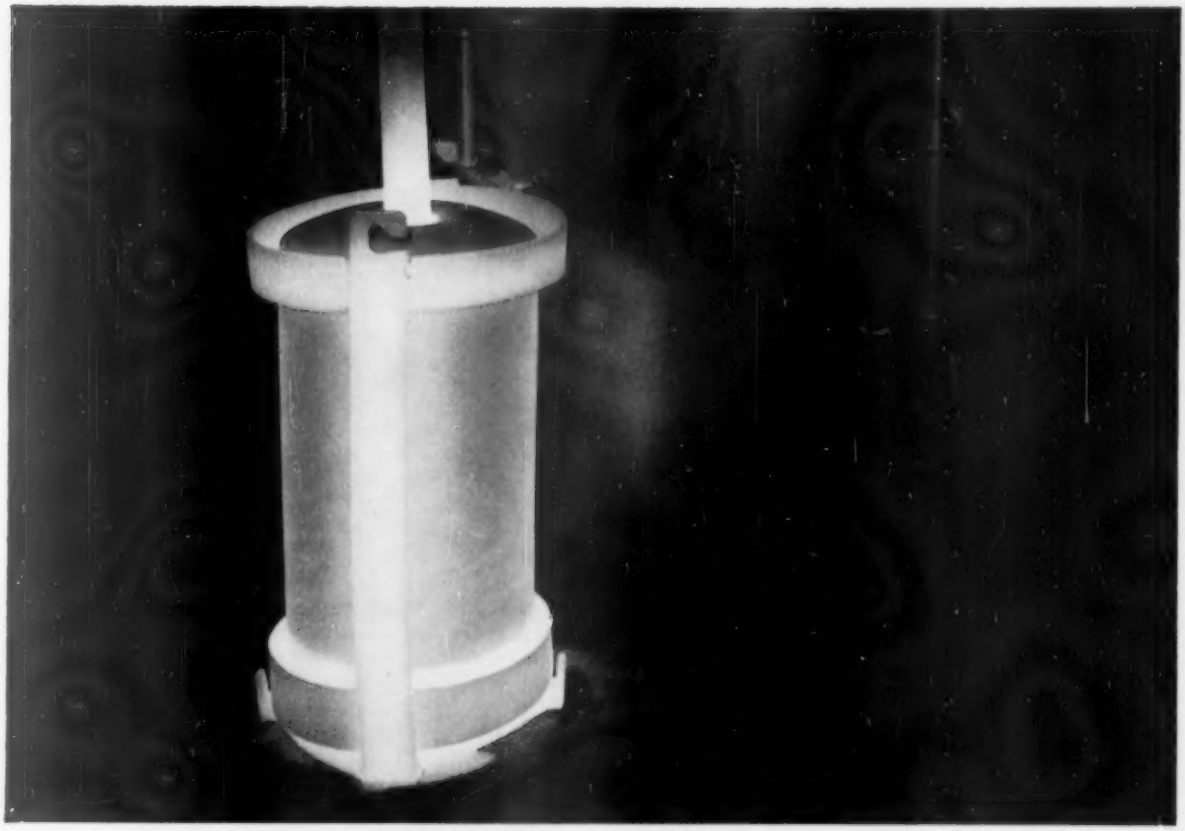


FIG. 2. This collimator, with Sr^{90}-Y^{90} point source, provides well defined pencil of β-rays, up to 10,000 cpm. With kerosene lubrication, hole in Lucite cylinder was bored with smooth-wall finish. Lead shield with central hole reduces bremsstrahlung but passes collimated β-rays; shielding is wrapped around sides of cylinder. Source is separated from mouth of hole by thickness of disk. Source assembly is then placed, source down, in wooden block, which shields sufficiently for safe handling and produces only weak bremsstrahlen



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How to Increase Sensitivity of Alpha-Particle Photographic Detection

By K. H. SUN and P. SZYDLIK
Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania

The photographic detection of alpha particles is usually carried out by microscopic observation of alpha tracks or by visual or densitometric examination of the photographic blackening. In the latter case, 10^6 alpha particles per cm^2 are required to give a barely visible photographic image on alpha-particle-sensitive nuclear emulsion. By using Kodak Tri-X film, a fast developing procedure, and a thin layer of ZnS-Ag, we can obtain an equal optical density while reducing the exposure time by a factor of 20 to 160, depending on the region of the optical density.

It is known that when an energetic charged particle, such as an alpha particle of a few Mev energy or a fission fragment, passes through a photographic emulsion, a track of the order of 10 microns in length and a fraction of a micron wide may be developed, requiring a high-powered microscope. If the number of alpha particles is large enough, say, of the order of $10^6/cm^2$, an image discernible from the background may be obtained in an alpha-sensitive emulsion.* By using Kodak Tri-X film and a fast developing procedure, the sensitivity of photographic detection may be increased about tenfold. However, one still requires about 10^5 alpha particles/cm^2 for a barely visible image.

In this direct photographic process, i.e., autoradiography, most of the ionization energy provided by the high-energy charged particles is concentrated in a small number of silver bromide grains. The energy input per grain in this case is far greater than that needed for the successful development of the photographic grains. Most of the energy, therefore, is wasted in this direct method of detection. This is particularly true for charged particles such as protons, alpha particles, or fission fragments.

To overcome this difficulty, the high-energy charged particle may be first converted into a large number of low-energy particles, which are equally reactive in the photographic emulsion. In this way, a larger number of grains are affected, thus achieving photographic amplification. This can be accomplished by inserting a layer of ZnS-Ag phosphor of about 10-micron thickness between the charged particles and the photographic emulsion, with an energy-conversion efficiency as high as 50%. The resulting light photons, produced in extremely large numbers, have much greater capacity for sensitizing the photographic grains than in the case without the ZnS-Ag phosphor, and thus photographic amplification is achieved.

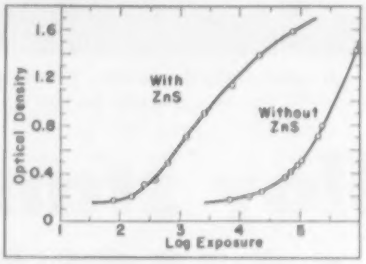


FIG. 1. Optical density of Tri-X film vs log exposure time for Po alpha particles with and without interposed ZnS-Ag phosphor film; source-to-film distance same in both cases

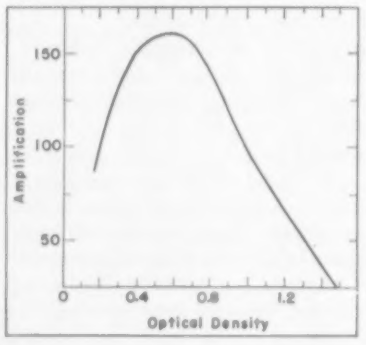


FIG. 2. Amplication (exposure time without ZnS/time with ZnS) of film sensitivity by ZnS-Ag; optical-density region for greatest amplification, i.e., where amplification is over 100, is 0.2–1.0

The alpha sources used were made from Po^{210} deposited in a very thin layer on 8-mm-diameter disks. The strengths of these sources were calibrated by counting the emitted particles with a scintillation counter in a 2π geometry and were all of the order of $110/cm^2/sec$.

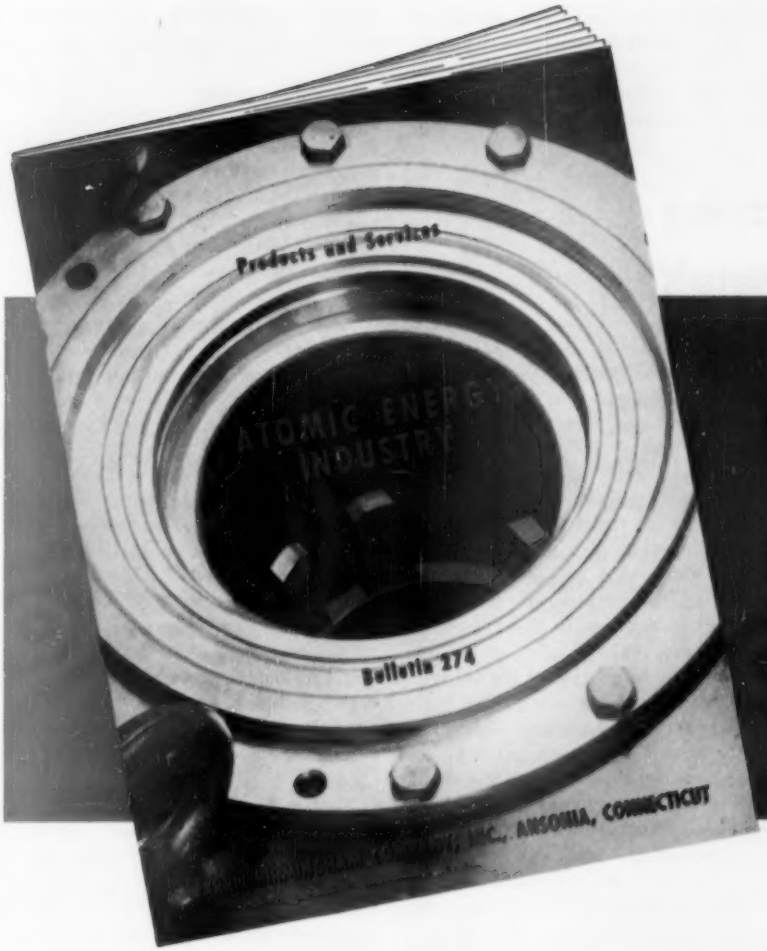
To measure the sensitivity of the improved autoradiographic technique as compared with the older method, twelve exposures were usually made on a single 3×5 in. Tri-X film. In the case where no ZnS-Ag was used, the longest exposures were of two weeks' duration. It was noted that short exposures, i.e., of a few hours' length, made either at the beginning or at the end of two weeks, showed no detectable differences in optical density, thus indicating that errors introduced by latent-image fading did not occur in this two-week period. The ZnS-Ag phosphor used was Du Pont 1410 (formerly 2B1). The phosphor powder was dusted on a Saran film (about 10 microns thick) previously coated with a very thin layer of Cello-stick, an organic binder. The phosphor film, essentially a monoparticle layer of ZnS-Ag supported on an equally thin layer of transparent Saran film, was placed on top of the alpha source with the ZnS-Ag side facing the source.

The photographic films were developed in Kodak SD19a developing solution. The development was made at 68° F for 20 min with continual agitation. The film was then rinsed and fixed in an acid fixer at 68–72° F for 20 min.

It is apparent from Fig. 1 that, for the same optical density, the exposure time with ZnS-Ag is considerably less than for that without it. The reduction of exposure time varies from 20- to 160-fold, depending on the region of optical density of the film. Figure 2 is a plot of the amplification, i.e., ratio of the exposure times without and with the ZnS-Ag, as a function of optical density.

With this technique, the number of Po alpha particles required to give a barely visible image in Tri-X film is reduced to about $800/cm^2$ or about $8/mm^2$. Because of the powdered form of the phosphor used, the image

* M. Yagoda, "Radioactive Measurements with Nuclear Emulsions," p. 20 (John Wiley & Sons, Inc., New York, 1949).



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tends to be grainy. It is anticipated that when a continuous transparent layer or film of phosphor is used, the photographic pattern will be much more uniform and attractive. The technique described here should be widely applicable in autoradiography and similar processes involving alpha particles or other charged heavy particles of high energy.

Apparatus for Studying Irradiated Liquid Metals

By R. J. TEITEL
Brookhaven National Laboratory
Upton, New York

The two liquid-metal fuels for power reactors currently under investigation in the Brookhaven Engineering Department are uranium-bismuth solution and intermetallic compounds of uranium dispersed in lead-bismuth-tin alloys.*

The effect of radiation on the uranium-bismuth solution would be expected to be nil. There is a possibility, however, that neutron irradiation may cause a change in the particle size of the intermetallic compounds. Of the uranium dispersions, those with USn_3 (an intermetallic compound of uranium and tin) as the solid phase have received the most attention. The properties of these dispersions are unique in that the solid and liquid phases have the same density.

Examination Method

Dispersions of USn_3 in tin were prepared by one of several methods.* The specimens, sealed in quartz under vacuum for irradiation, were examined metallographically before and after irradiation. Consequently, a procedure was developed for preparing and taking photomicrographs of specimens in the presence of α-, β-, and γ-radiation.

The metallographic preparation takes advantage of the soft matrix of the alloys, provides for little scatter of radioactivity and simplicity of operation, and is inexpensive. The heart of the technique, as in any microtome application, is the grinding of the tool bit and the orientation of the bit relative to the specimen (see Fig. 1).

The radioactive specimen (*E*, Fig. 1), in the form of a ¼-in.-diameter, ½-in.-long cylinder, is loaded into the chuck (*F*) with the manipulator; the chuck is closed by an Allen wrench (*G*) extending through the lead wall. The tool bit is ground at the proper cutting angle in a jig on grinding wheels and emery paper outside the cell. By means of the manipulator, the bit is slipped into the holder (*B*), which sets the cutting edge at the proper angle to the sample. Another Allen wrench (*H*) is used to close the tool holder and clamp the tool bit firmly in place. The traverse and advance feeds for the tool stage are actuated by means of two flexible couplings (*I* and *J*) to shafts extending through the lead shield.

The tool bit (Fig. 1) is positioned in front of the specimen by means of the stage feed and moved into the specimen by the stage advance. A flat cut is made. To determine whether the cut is free from dragging or deep scratches, the microscope is moved into position and the surface is viewed on a ground glass on the operating face of the shield (Fig. 2).

After the proper cut is made, the etching tank is moved in front of the specimen and the specimen forced into the tank through a rubber-lined hole in the front of the tank. Etchant is applied to the specimen by means of a daub held in the manipulator and moved in and out of the tank from the rear. Washing and drying is done with a spray of water followed by an alcohol spray and an air blast delivered through the nozzles on top of the etching tank.

Photomicrographs are taken by moving the microscope into line with the specimen. After the microscope light is switched on and the room darkened, the structure is observed on a ground-glass plate on the other side of a lead-glass window. The microstructure is projected through this window by means of the prism located over the eyepiece of the microscope. Since the axis of the microscope is parallel to that of the ground glass, focus adjustments

* R. J. Teitel, D. H. Gurinsky, J. S. Bryner. Liquid metal fuels and breeder blankets, NUCLEONICS **12**, No. 7, 14 (1954).

FIG. 1. Lathe is behind lead shield (*A*) in semihot, hooded cell. Tool holder (*B*), plastic etching tank (*C*), and microscope (*D*) are mounted on tool stage. Cell is serviced by motor-driven, rectilinear manipulator; hand-operated manipulator could be used

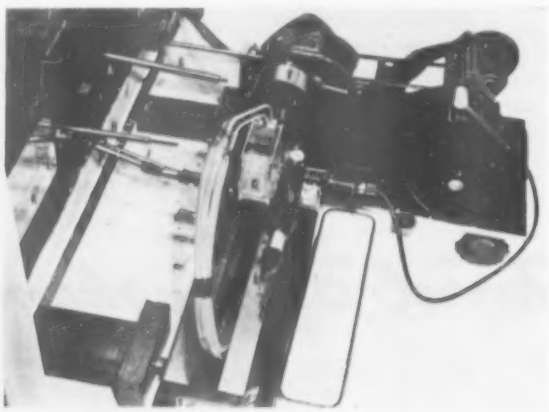

FIG. 2. On operator's side of cell wall are controls for lathe and for visual examination, ground glass for observing microstructure (*A*), stage advance (*B*) and traverse (*C*) adjustments, tool extensions for chuck (*D*), tool holder (*E*), and manipulator (*F*)

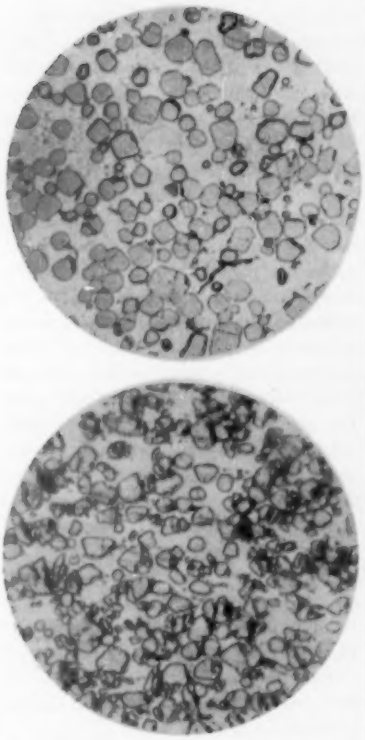

FIG. 3. Photomicrographs of alloy containing USn_3 particles in Sn prepared by conventional etch polish method (top) and by lathe (bottom). Even though there are some scratches and fragmentation in lathe-prepared structure, general particle size agrees with that of hand-polished specimen

are made by adjusting the stage advance. With the structure in focus, a photographic plate is substituted for the ground glass and exposed for a period regulated by the microscope light switch.

Results

Fragmentation and scratches on the specimen (Fig. 3) indicate that more development work is needed. Thus far, only Momax tool bits have been used. It is planned to try Carboloy as well as other tool steels.

This method of preparation can also be used to prepare samples for electrolytic polishing and etching techniques. As an example, O. Kammerer of the Brookhaven metallurgy group has demonstrated that uranium-tin-lead alloys can be electrolytically polished and etched with an anhydrous sodium acetate, glacial acetic acid electrolyte.

* * *

The success of these techniques is largely due to the assistance of W. Stapf, who assembled all the necessary equipment. The author also wishes to thank J. S. Bryner and C. K. Pospisil for their suggestions in the early days of this work.

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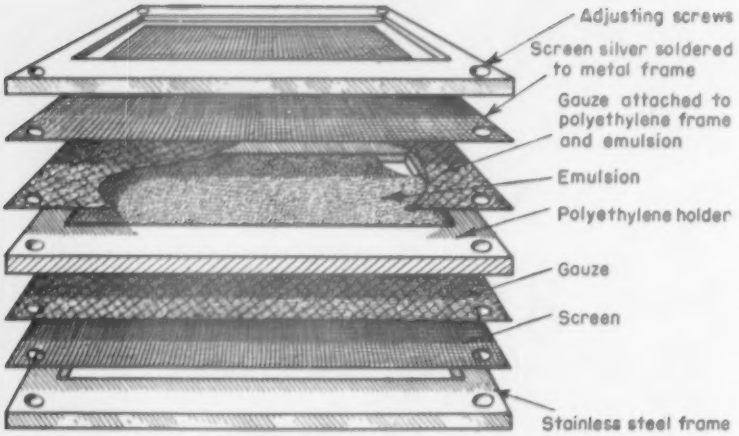


FIG. 1. Nuclear emulsion pellicle mounted in holder

Bilateral Development of Thick Nuclear Emulsions

By R. FOX and R. W. WANIEK
Harvard University
Cyclotron Laboratory
Cambridge, Massachusetts

In the past, the major limitations in the use of thick nuclear emulsions resided in the intricacies of the development as well as in the nonavailability of long-working-distance objectives with large magnifications. With the advent of long-working-distance optics (e.g., Koristka 55×, N. A. 0.90, 1,350 microns w.d. objective), it became profitable to seek improvements in development techniques and to extend the range of developable emulsion thicknesses. The main requirements imposed on the processing of thick nuclear emulsions involve a homogeneous development with depth, a low level of distortion and a favorable ratio of signal-to-background grains with reasonable development times.

To fulfill these conditions and to gain a conspicuous factor of 2 in the developable thickness (the other parameters remaining the same), we resorted to a method of processing nuclear emulsions bilaterally.* With this method emulsions of 2,000 microns have been developed satisfactorily.

Figure 1 illustrates the principle we have adopted. A gauze impregnated with a Duco-acetone solution is applied to each side of a pellicle. To prevent the gross lateral expansions that occur in the early stages of developing, a thin strip of Duco cement is applied along the edges. The gauze then constrains the pellicle. To prevent the contractions that set in during the hypo stage, the gauze is also attached to a polyethylene frame. A pellicle expands over two times in thickness during developing. To prevent buckling due to this large increase in volume, the pellicle with the attached polyethylene frame is placed in a stainless-steel holder. The sides of the pellicle are facing stainless-steel mesh, which allows a free exchange of the salts in the developing bath with the pellicle.

During the presoaking stage, when the main expansion occurs, the mesh is raised slowly enough so that the faces of the pellicle are always flat against it. The jig is sent through a continuous low-temperature development that has been used at this laboratory during the past few years.† The essential feature of the process consists in allowing the developer to penetrate at temperatures slightly above the freezing point of water and to use properly the slow developing action to ripen the grains. Thus, for a 1,000-micron pellicle or a 400-micron glass-backed emulsion, the development is 4½ hr at 4° C using 1:3 ratio of D19 to water.

After the stop bath, the pellicle with the attached polyethylene frame is removed from the stainless-steel holder. The central gauze is cut away, and the fine-grain silver that comes to the surface is gently removed. In the ensuing hypo stage, only contractions set in that can be adequately stopped by the polyethylene frame strengthened by the stainless-steel frame (Fig. 2).

To determine the level of distortion present in the emulsion using this development technique, scattering measurements were made on the tracks of high-energy particles found in the emulsion. Testing for the presence of "C"-shaped distortions, localized within a region of a few hundred microns or less, cell lengths of 25 microns were used. The measurements all fell below the setting error of the microscope (Koristka MS-2). For the high-energy tracks, 500-micron cells are used to get above the setting error. The criterion of dis-

FIG. 2. Preparatory to hypo bath, central gauze is cut away from pellicle

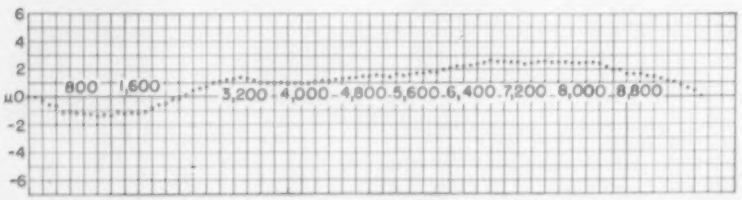


FIG. 3. Coordinates of projected track due to 1.7-Bev π-meson (both scales in microns)

* R. Fox, R. W. Waniek, *Bull. Am. Phys. Soc.* **30**, 14 (1955).

† E. G. Silver, R. W. Waniek, *Rev. Sci. Instr.* **25**, 119 (1954).

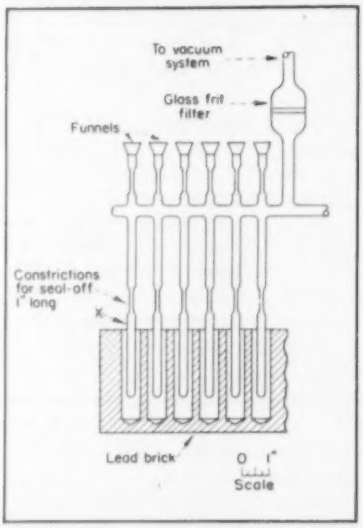
tortion adopted was to take the algebraic average of the second differences and compare these with the standard deviation of the average of the absolute second differences. This criterion was applied to a number of tracks. The algebraic average was of the same size as that of the standard deviation of the absolute average.

In Fig. 3, the first and last points of a track were anchored on a straight line and the position measurements plotted. It is a 1.7-Bev π-meson, as determined from the scattering measurements. The maximum deviation of the track from the axis is 2.5 microns over a length of 10,000 microns, which is a tangible proof for the low level of distortion encountered with this new technique.

* * *

This work was supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

Sample Storage



SEALING RADIOACTIVE SPECIMENS IN GLASS AMPOULES avoids sample oxidation and spread of radioactive contamination. With ampoules on manifold extending into holes in lead brick, samples are dropped in through funnels. Using crucible tongs and flame, seal off upper constrictions, discarding funnels. Evacuate ampoules and, if desired, backfill with inert gas. Grasp each ampoule at X with tongs, seal off from manifold and after cooling drop ampoule gently into hole. To open ampoule grasp near top with tongs and insert specimen end in hole in lead brick; score exposed end with file and break off with sharp blow. MYRON B. REYNOLDS *Knolls Atomic Power Laboratory (operated by the General Electric Co. for the U. S. Atomic Energy Commission under Contract No. W-31-109 Eng-52), Schenectady, New York*

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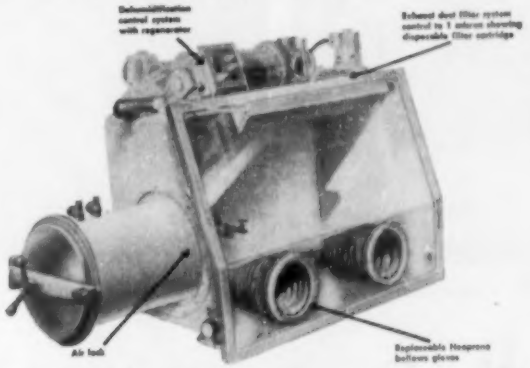

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WELL COUNTER accommodates 1-gal jar; 12 G-M tubes, in two tiers of 6 each, surround cylindrical well

G-M Well Counter for Determining Activity in Large Volumes

By E. V. WEINER and R. E. PETERSON
Radioisotope Unit
Veterans Administration Hospital
Iowa City, Iowa

In applying radioisotopes to medical diagnostic procedures, the urinary concentration of a particular isotope is often measured, usually using an aliquot of the sample as well as the entire sample volume. A G-M well counter allows routine measurements of urinary excretion, as well as other biological products of considerable volume, thus avoiding sample pipetting, drying, and computations involving the over-all dilution.

In the well-counter method, the over-all activity is counted and compared to a suitable dilution of the original isotope. Veall and Vetter (*1*) described an apparatus for measuring the radioactivity in liquid samples contained in 3-liter bottles. This apparatus consisted of 6 verticle G-M tubes arranged in a circle. They measured I^{131}, Na^{24}, and P^{32}.

Counter Construction

A well counter was constructed (Western Radiation Lab., Los Angeles) using 12 bismuth-enriched-cathode G-M tubes (Victoreen 6306). Six tubes are in a circle around the base with another six above them, thus creating a hollow cylinder surrounded by 12 tubes. The cylinder, 7½ in. in diameter by 11 in. deep, can hold a 1-gal screw-cap jar. The difference between the jar diameter and the inner well diameter permits inserting cylindrical absorber material to reduce coincidence losses due to high activity concentrations.

The tubes are so connected that 6 at a time may be in use. The groups of 6 are so arranged that a symmetrical trio in each bank is functioning. In this fashion, the two halves may be tested or used independently, or the entire 12 for maximum sensitivity.

The bismuth-enriched G-M tubes allow counting gamma as well as beta-emitting isotopes. The tubes are also sensitive to bremsstrahlung produced by the absorption of weak betas in the glass wall of the jar and the liquid. Containers of lesser wall density than glass, such as polyethylene, may also be used to increase beta counting rate.

The construction of the counter consists of a durable insulating plastic base. The outer vertical wall is a thin sheet of metal. At the top, a plastic insulating ring is joined to the wall.

TABLE 1—Well Response With and Without 6-mm Lead Filter

	Sensitivity			*Efficiency (%)*	
	With inner filter (cps/μc)	*Without inner filter (cps/μc)*	*Minimum activity detected (μc)*	*With inner filter*	*Without inner filter*
I^{131}	4.3	42.0	0.17	0.01	0.1
P^{32}	20.0×10^{-3}	550.0×10^{-3}	13.00	5.42×10^{-5}	1.48×10^{-3}
Fe^{59}	20.0	38.5	0.19	0.05	0.10
K^{42}	70.3	27.0	0.27	0.19	7.3×10^{-2}
Na^{24}	11.9	19.2	0.38	3.22×10^{-2}	0.05

TABLE 2—Comparison of Detectors for I^{131}

Detectors	*Minimal activity detected (μc)*	*Activity in sample (μc)**	*Maximal sample volume (ml)*
Marinelli 2π counter	0.01	0.004	40
"Texas" 4π counter	0.002	0.008	75
High-pressure ion chamber (4π)	0.1	0.02	200
Quartz-fiber electroscope	0.0008–0.0009	0.001	10
Mica end-window G-M counter (liquid samples)	0.001	0.001	10
Mica end-window G-M counter (dry samples)	0.0001	0.001	10
Scintillation counter (liquid samples)	0.04	0.001	10
Scintillation counter (dry samples)	0.13	0.001	10
Gas-flow proportional counter	0.00016	0.001	10
G-M well	0.17	0.2	2,000

* Total activity in sample based on 0.2 μc in 2,000 ml.

The inner wall, perforated thin sheet metal, is removable. The perforated metal protects the G-M tubes while allowing considerable area for the more energetic beta particles to reach the tubes. Six tubes are fastened to the plastic base, equally spaced, and 6 tubes are fastened to the plastic ring at the top, equally spaced. The two rings are staggered for easy removal of individual tubes. An outer, $1\frac{5}{16}$-in.-thick lead shield reduces background. An ordinary scaler recorded results.

Operating Characteristics

The well-counter response was checked with 0.2–100 μc of I^{131}, 0.2–2.2 mc of P^{32}, and 0.52–5.1 μc of Fe^{59}. The counting rate was linearly proportional to the activity present. Determinations made with various concentrations and volumes of I^{131}, P^{32}, and Fe^{59} showed that at about 2,000 ml the counting rate does not change significantly.

A 200-ml sample of I^{131} solution was counted in the well at various distances above the bottom. The most sensitive area is at the half-way point. The optimum method, though, is to add sufficient liquid, when necessary, to bring the volume to 2 liters.

Sensitivity. Table 1 shows the well sensitivity and efficiency for several activities in 2 liters of water. The inner filter (6-mm lead) can be used for high activity concentrations. The sodium iodide crystal well of the usual $1\frac{3}{4} \times 2$ in. with a $\frac{3}{4}$-in. hole, $1\frac{1}{2}$ in. deep, can count 4-ml samples with greater efficiency. However, where the initial sample is of the order of 2 liters, the G-M well offers advantages in sensitivity, as well as simplicity of sample preparation.

If we multiply the efficiency of a detector (%) times the amount of activity present, the application of the well for large volumes is shown. Let the activity be present in a 2-liter sample. The G-M well takes the entire sample, and the crystal well, 4 ml ($\frac{1}{500}$ of activity present). Thus, these products would be, for I^{131}, Fe^{59}, and P^{32}, 1×10^{-3}, 1×10^{-3}, and 1.15×10^{-4}, respectively, for the G-M well and 7.5×10^{-4}, 4.8×10^{-4}, and 3.61×10^{-6}, respectively, for the crystal well (*2*).

Bruner and Perkinson (*3*) evaluated many detectors for I^{131}. Table 2 compares them with the G-M well.

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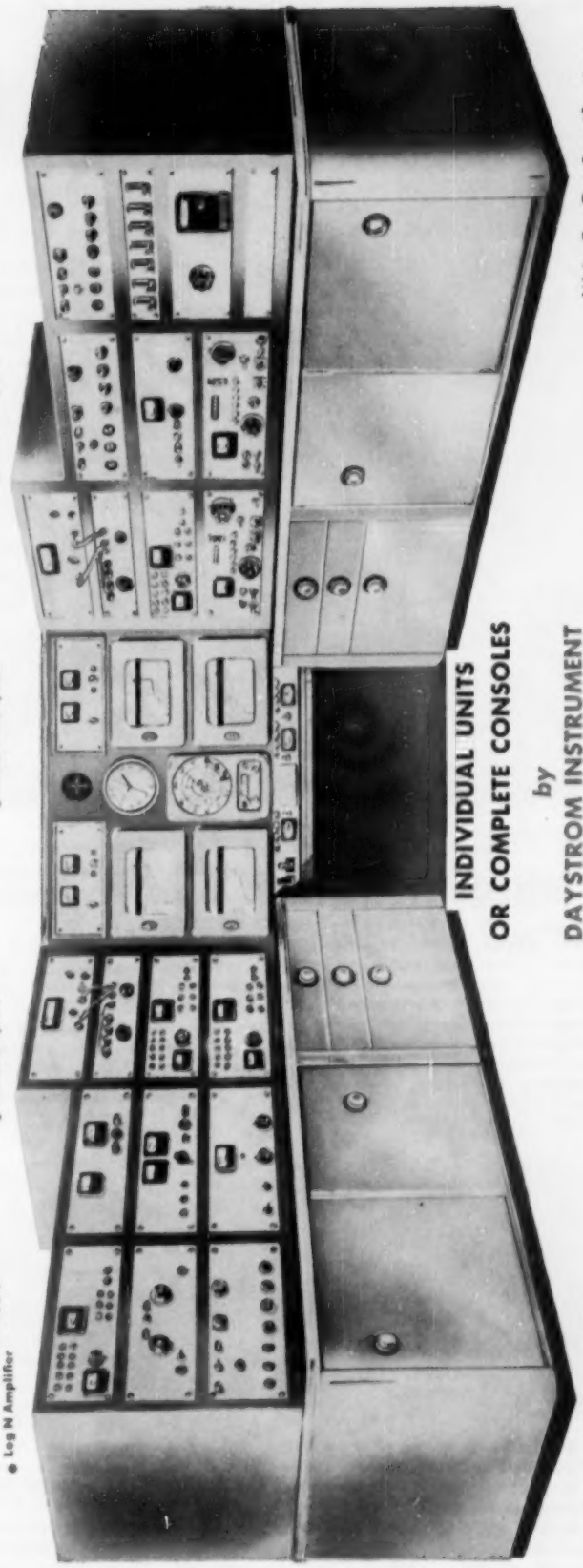

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Photographic Recording Method for Scintillation Scanning

By NORMAN H. HORWITZ and JAMES E. LOFSTROM
Department of Radiology
College of Medicine, Wayne University
and Detroit Memorial Hospital
Detroit, Michigan

Several methods have been used to convert the impulses from a scintillation counter into a visual representation of a radiating area (*1–3*). In the method reported here, the radiating area is reproduced by building up a pattern of dots on ordinary photographic enlarging paper. The dots are produced by the light that accompanies the firing of a Strobotron discharge tube.

The pulses from the scintillation counter, after passing through a preamplifier and a pulse-sharpening circuit, actuate a one-shot multivibrator. The output from this triggers a strobe-tube firing circuit. The cold-cathode-type discharge tube, a Sylvania 1D21/SN4, is capable of firing about 240 times a second. Light from the discharge tube then illuminates a diaphragm, an image of which is formed on the photographic paper by a microscope objective (Fig. 1).

A scanner using this recording system is shown in Fig. 2.

This method of recording has several advantages:

1. Since there are no mechanical parts, the limitation on operation rate created by the inertia of a mechanical recorder is removed.

2. A scaler is not required with this device. All counts are recorded and the overlapping of the dots produce the image.

3. A full-size recording is obtained on a rather inexpensive paper.

4. The entire instrument is not unduly costly.

* * *

This work was aided by a grant from the Receiving Hospital Research Corp.

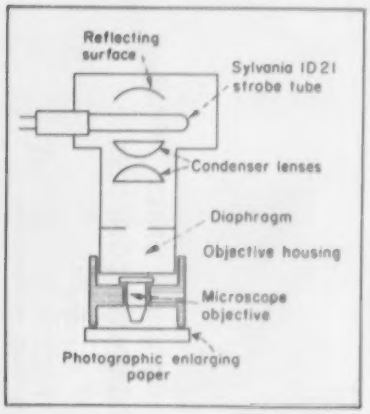

FIG. 1. Short focal length of microscope objective, which forms image on photographic paper, makes objective-paper distance critical for uniform dot size. To assure constant spacing, objective housing—free to travel vertically over tube housing—glides over paper, following irregularities; this permitted minimal precision machining and critical adjustment of scanning mechanism. Edge contacting paper is highly polished to prevent marring emulsion

FIG. 2. Recording device of this scanner is in light-tight housing consisting of bellows made from plastic curtain material. Preloading photographic paper in 8 × 10 in. cut-film holders permits operating scanner in undarkened room; cut-film-holder compartment is to left of patient

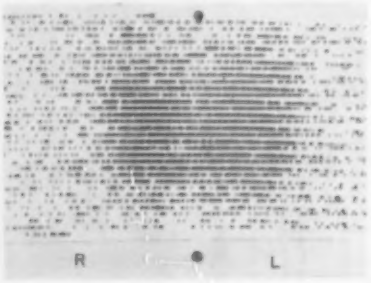

FIG. 3. Recording of thyroid gland. Light intensity can be adjusted so that single flash shows up as gray dot. Only where dots pile up is there blackening. Thus, radiochemical deposition in organs can be quantitatively and qualitatively estimated. Heavy dots are markers

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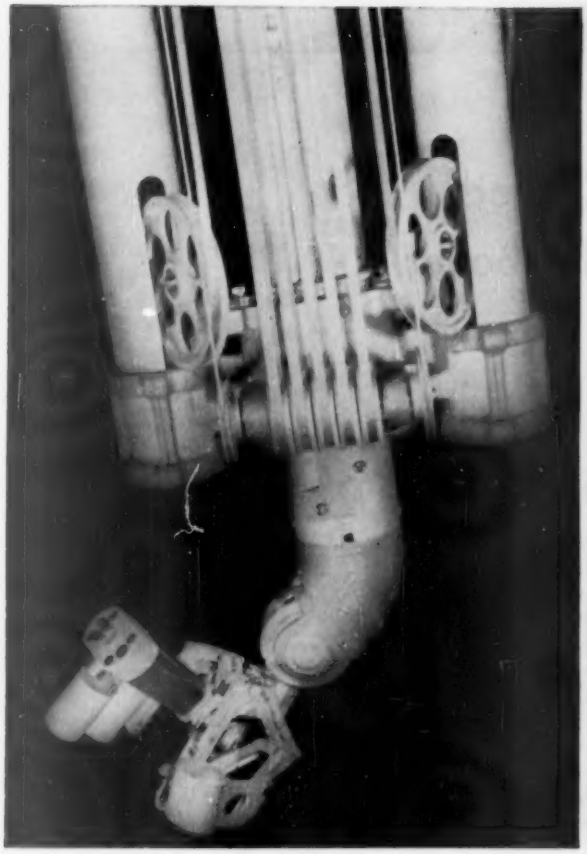
TECHNICAL BRIEFS

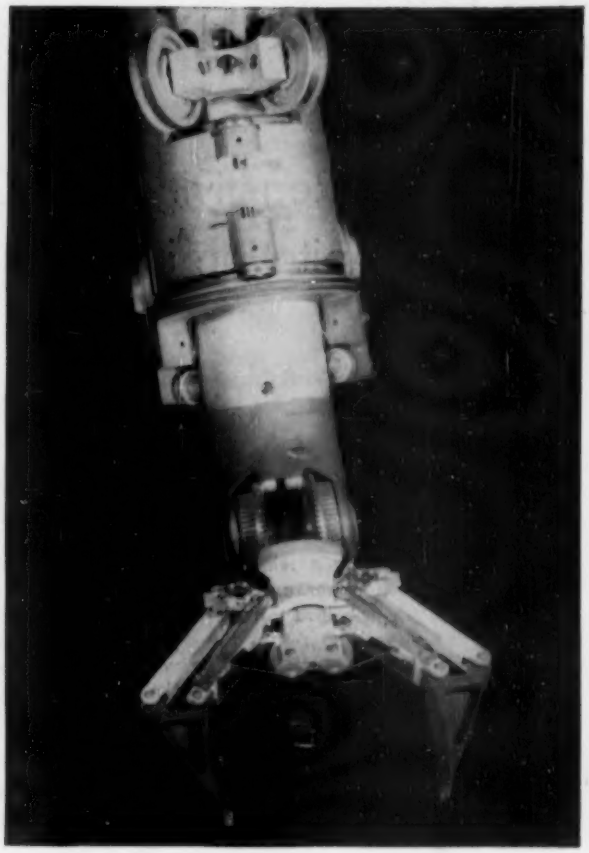
Beta rays promising for brain cancer treatment. Yttrium-90 may be more effective than surgery in treating glioma, reports Paul V. Harper, University of Chicago. Thus far, Y^{90} beads have only been implanted in the brain of a cat.

High-temperature viscometer uses radioisotope timer. The time of fall of a plummet containing Co^{60} is determined by means of two sets of coincident ionization chambers and an electronic timer. The fall tube is contained in a stainless-steel pressure vessel with an upper limit of 3,000 lb/in² and 300° C. J. R. Heiks and E. Orban (Mound Laboratory) have used the viscometer to measure benzene viscosity up to 288.5° C (the logarithm of the viscosity vs reciprocal of the temperature is linear up to 180° C; above this, the rate of change increases with increasing temperature).

Rapid method provides continual supply of carrier-free yttrium-90. By periodic "milking" of strontium nitrate, M. L. Salutsky and W. H. Kirby (Mound Laboratory) obtain a 95% Y^{90} yield exhibiting a 64-hr half-life. The Sr^{90} received in a Sr^{90}-Y^{90} equilibrium chloride mixture is purified by nitrate precipitation in 80% HNO_3 with inert strontium carrier, followed by two homogeneous chromate precipitations with barium carrier (the precipitations remove all contaminants except Sr^{89}, which decays to stable Y^{89}). The purified strontium is reconverted to nitrate and set aside to allow Y^{90} growth. The Y^{90} is then separated by strontium nitrate precipitation in 80% HNO_3 and recovered from the filtrate. At least two weeks are recommended between extractions.

Phosphorus-32 easily extracted from pile-irradiated sulfur. Irradiated, finely powdered sulfur is boiled with water containing a nonionic wetting agent. Owing to the rhombic-monoclinic transition point of sulfur at 95.5° C, the phosphorus diffuses out of the solid material in 1–2 hr and is extracted into the water. Sulfur-35 remains in the target material. With a sulfur particle size of 5 microns, yields over 80% are obtainable. According to K. Samsahl and K. Taugbøl (Joint Establishment for Nuclear Energy Research, Kjeller, Norway), the extraction requires only about 3 hr and will be adopted for routine production at JENER.





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Preventing Reactivity Loss Caused by U Precipitation in a Water Boiler

By CLIFFORD K. BECK, *North Carolina State College, Raleigh, North Carolina*

Reactivity of the Raleigh Research Reactor dropped below critical when the uranium in the aqueous fuel solution precipitated during a relatively low-temperature high-power run. Addition of metallic ions helped to redissolve the precipitate and return the reactor to criticality.

Although the Raleigh Research Reactor operated initially on September 5, 1953, it was operated at power levels of 100 watts or less until July 26, 1954. During this period reactor characteristics were determined, instruments and auxiliary apparatus were calibrated, and satisfactory operating and experimental procedures were developed.

How reactivity dropped. On August 3, after 1 hr of experimental operation at about 400 watts, the reactor began to lose reactivity during an experiment in which the reactor was operated with widely varying core temperatures. The loss of reactivity began when the fuel-solution temperature lowered to 11° C. The loss was slow at first and then increased. The first indication of loss of reactivity was observed in the gradual withdrawal by the automatic controls of the control rod from its normal 7.5-in. out position. After about 1½ hr the rod had been withdrawn the full 12 in. and the reactor became subcritical.

The fuel solution in the reactor core at the time was uranyl sulfate (848 gm U^{235}; >90% enrichment) dissolved in 13 liters of ordinary water. At 400 watts, the power density was about 30 watts/liter in the fuel solution containing 65 gm U^{235}/liter. The *p*H, measured sometime prior to the incident, was 2.3. Total reduction of reactivity was equivalent to the removal of about 40 gm of U^{235} from the core.

Finding the cause. It was suspected immediately that the loss of reactivity might be due to partial precipitation of the uranium fuel as uranyl peroxide, $UO_4 \cdot 2H_2O$. The higher power level of operation would have been conducive to formation of a larger concentration of hydrogen peroxide, and the low temperature of the solution tended to prevent decomposition of H_2O_2. Thus, the reaction of H_2O_2 with UO_2^{++} to form enough uranyl peroxide for a precipitate to occur would have been favored. But other possible causes for the loss were explored.

Fear of a leak in the fuel cylinder was removed by: (a) checking the liquid level in the fuel cylinder; and (b) an indication from a previously installed electrical resistance probe that no liquid had collected in the safety envelope surrounding the fuel cylinder. Other possibilities eliminated include: (a) unusual accumulation of xenon in the fuel cylinder, and (b) penetration of catalyst dust from the H_2-O_2 recombiner loop through the filters so that the dust collected in the fuel cylinder.

Definite establishment that partial precipitation of the uranium caused the loss of reactivity was obtained in several ways.

1. The *p*H of the solution was found to be 1.3 instead of the normal 2.3. This shift to a more acid condition is what should have accompanied uranium peroxide precipitation, since hydrogen ions are produced in the solution by the chemical reaction yielding peroxide. The change in value of *p*H suggested that more uranium peroxide may have formed than seemed to have been removed from the system. Probably only a portion of the precipitated uranium peroxide settled out, while the remainder continued in a dispersed condition.

2. A temporary increase in reactivity was caused by bubbling air through the sampling tube terminating in the lower portion of the fuel volume. This would have been expected if a settled precipitate were temporarily stirred in a local area by bubbles from the tube.

3. Slight cloudiness in a sample withdrawn from near the bottom of the fuel solution indicated a fine particulate suspension not observable in a sample from near the top of the solution.

Redissolving the precipitate. For two days following the loss of reactivity, efforts to redissolve the precipitate were unsuccessful. The solution temperature was raised to 80° C by circulating hot water in the cooling coils and stirring the solution by bubbling air through the sampling tubes. Several times, after extended application of these measures, sufficient reactivity was regained for the reactor to become critical. But reactivity always was lost again after a few minutes operation.

In discussing the situation with representatives of the Oak Ridge National Laboratory (*1*), it was suggested that certain metallic ions be added to the fuel solution. The metallic ions would catalyze the dissociation of peroxide formed in the solution. Thus, it was suggested that adding 8–10 ppm each of cupric and ferrous ions would promote reversal of the precipitation reaction and reduce the likelihood of further precipitation of uranium.

On August 9, 1.2 gm of cupric sulfate and 1.75 gm of ferrous sulfate were added to the reactor solution. After this, air was bubbled through the sampling tubes and temperature was cycled to assist stirring. While maintaining a temperature mostly at 75–80° C, the precipitate was dissolved. The dissolution was slow at first—only 1 or 2 gm of U^{235} equivalent gain in reactivity per day. But it speeded up

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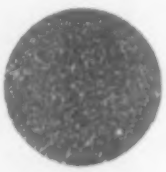
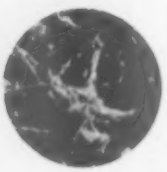
Photomicrograph of Millipore Filter surface. Magnification approximately 100 x



Photomicrograph of dense high quality filter paper surface. Magnification approximately 100 x



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to 14 gm/day. By August 16, the total reactivity had been regained. The solution *p*H also returned to a value near the original.

Over the succeeding two weeks, the reactor was operated at a temperature of 35° C for a total of 60 kwh at levels up to 500 watts. Later it was brought up to 7 kw at 35° C. There was no further evidence of precipitation.

Cause of Difficulty

The effect of radiation on the water of aqueous fuel solutions of homogeneous reactor assemblies, with the consequent products formed and the possible subsequent reactions that may occur between these products, encompass phenomena that may set upper limits on the power level of such systems. Results of two different phenomena, gas formation and H_2O_2 formation, are of particular importance.

Gas formation. At atmospheric pressure and low temperature, gases (mostly H_2 and O_2) form, collect into bubbles, and rise to the surface of the solution. These bubbles reduce solution density, which in turn lowers nuclear reactivity. In small research reactors operating at atmospheric pressure, a sufficiently large instantaneous gas-bubble inventory could reduce reactivity to such a point that operation at the desired level would not be possible.

H_2O_2 formation. Chemical reactions likely to occur after formation of H_2O_2 could cause precipitation of the uranium. This is the phenomenon responsible for the incident reported here.

The effects when water is exposed to radiation are extremely complicated (*2*). Consequent reactions are even more complicated by other materials in reactor fuel solutions.

The primary effects of radiation on water might be divided into two categories, characterized by the reactions

$$2H_2O \rightarrow H_2 + H_2O_2$$

or

$$2H_2O \rightarrow 2H + \tfrac{1}{2}O_2 + H_2O$$

$$2H_2O \rightarrow 2H + 2OH$$

Under the conditions prevailing inside a reactor core, at least a considerable proportion of the effects may be described by the first equation. As higher power densities are reached, the amount of H_2 released and the amount of H_2O_2 formed increases.

As H_2O_2 is formed it may react with other components present. For example, with uranyl ion, uranyl peroxide is formed

$$H_2O_2 + UO_2^{++} \leftrightarrows UO_4 + 2H^+$$

If enough UO_4 forms, the material appears as a precipitate of $UO_4 \cdot 2H_2O$. However, once uranyl peroxide is formed, it may be decomposed again if favorable conditions prevail. Several processes might be visualized

$$UO_4 + 2H^+ \rightarrow UO_2^{++} + H_2O_2$$
$$UO_4 \rightarrow UO_3 + \tfrac{1}{2}O_2$$
$$UO_3 + 2H^+ \rightarrow UO_2^{++} + H_2O$$

But the peroxide may be decomposed as it is formed, and the concentration may remain sufficiently low that no appreciable reaction with UO_2^{++} occurs. This is the desirable condition in a reactor.

Increase in temperature, increase in acidity, and the presence of catalytic impurities are among the important conditions that would tend to lower the concentration of peroxide. Although information is not available on the optimum adjustment of these conditions or on the upper limits of reactor operation possible under optimum conditions, conditions can be established to permit homogenous reactors to operate at power densities greatly exceeding those reported here (*3*, *4*).

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REACTOR FACTS

Use of carbon steel in reactor circuit could cut costs. Emphasis is being placed by Babcock & Wilcox Co. on developing carbon steels of sufficient corrosion resistance to displace more costly stainless steel for reactor pressure vessels and primary loops. An all-carbon-steel loop figures in the study; and a similarly materialed reactor heat-transfer and corrosion mockup is being built with stainless simulated fuel elements. Other tests on carbon steels include: thermal cycling between 680 and 750° F and exposure in 600° F water with periodic exposures to air. Latter simulates refueling conditions.

Other materials aren't being neglected. Learning how boiling at the metal surface affects zirconium in 600° F water is object of other tests. And group is set to extend corrosion data on aluminum, including new alloys, to the range 500–600° F.

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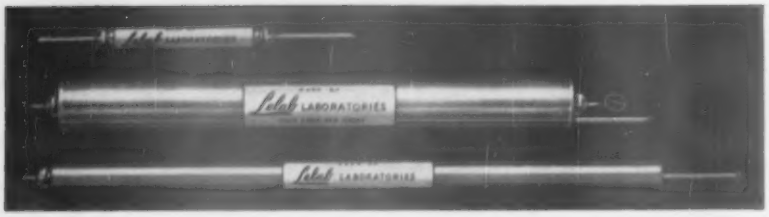

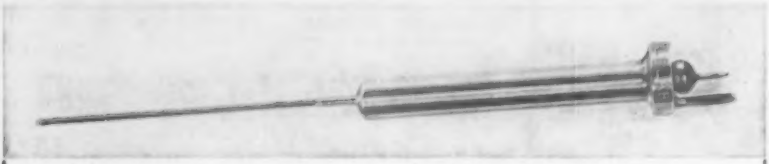

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600° F) so as to cut losses involved in cooling the primary-coolant bypass below 100° F when removing corrosion products with resin beds.

Optimism is felt about success of new gasketed closure for pressurized reactor vessel. Elimination of need to weld closure could reduce fuel-change-shutdown time from its present days to hours.

Gamma radiation either inhibits or accelerates corrosion. Results of exposing aluminum, copper and mild steel to corrosive solutions in 2.5–3 $\times 10^5$ r/hr fields of Co^{60} γ-rays show that either protective or nonprotective action is caused by the ionizing radiation. Where corrosion inhibition depends on a protective oxide surface film being formed (such as on Al in water), radiation exerts a protective effect because it makes the fluid more oxidizing. Where no protective film is formed in a system in which corrosion is rapid normally, radiation accelerates it, probably because of increased depolarization effects caused by radiation-induced decomposition products. These conclusions are drawn by F. Hittman and O. A. Kuhl of Brookhaven National Laboratory in BNL-2256. The experiments were made after it was noted that the irradiated portion of an underwater irradiation tube was free from hydrated-aluminum-oxide deposits that readily were visible in the unirradiated zone.

Samples of 24ST aluminum irradiated at 3×10^5 r/hr for 42 days in room-temperature tap and distilled water gained less weight than control samples. Metallographic examination showed that surface pits were shallower in the irradiated samples, and thus confirmed the analysis that they were corroded less than the control samples.

A dense surface oxide formed on both control and irradiated samples of 1020 mild steel in a solution of fused $NaNO_3$ at 350° C. Dose rate was 2.5×10^5 r/hr for a total dose of 5×10^7 r. The oxide layer was darker and more dense on the irradiated sample, which gained 3.0 mg, compared to 1.9 mg for the control. This indicates that the radiation caused a slight inhibiting effect. Some $NaNO_3$ decomposes to $NaNO_2$ in a radiation field, and $NaNO_2$ acts as a passivator for steel.

Copper in 2*N* HCl at room temperature was investigated under the same dosage conditions. The irradiated system showed a much greater attack than the control. For the irradiated sample, weight loss was almost

10 times as large. Substituting 1020 mild steel for copper, an increased attack in the radiation field was noted. Weight losses were 5.23 gm compared to 2.84 gm for the control.

Increased attack of irradiated Cu is caused by the greater amounts of oxidizing agents in the solution. Attack on Cu is largely dependent on the presence of an oxidizing agent. Reason for the accelerated corrosion of the steel is not clear. Probably, the oxidizing free radicals and H_2O_2 formed by radiation depolarize the cathode. Steel corrosion is cathodically controlled.

Benzene held not feasible as thermodynamic medium for nuclear plant. Although it would be desirable to replace water, which reacts violently with sodium, with a nonreactive fluid in a sodium-cooled reactor's power cycle, benzene seems unsuitable because: (a) a benzene cycle probably would be more expensive than the NaK and steam plant it replaces, largely because its heat-transfer properties are inferior to those of water and steam; (b) sludge deposits would require special cleanup provisions, (c) benzene, because of its flammability, introduces operating and maintenance hazards; (d) recombination or makeup would be needed because gammas from the sodium would dissociate benzene; (e) development of nuclear system shouldn't be complicated by problems of developing a benzene system. If carbon and hydrogen from the benzene get into the sodium coolant of a fast reactor and moderate neutrons, the reactor could tend to go prompt critical. These conclusions were expressed by I. G. McChesney of Rochester Gas and Electric Corp. and R. H. Shannon of United Engineers and Constructors at a meeting of the American Society of Mechanical Engineers.

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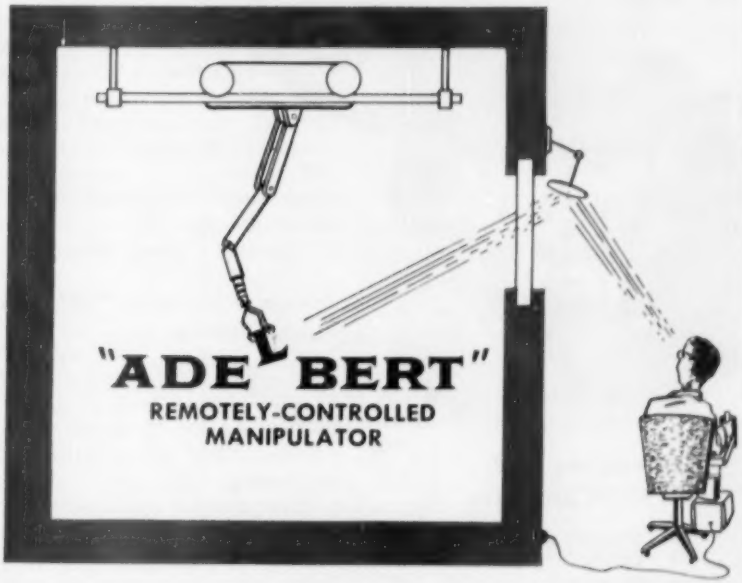

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TECHNICAL ADVANCES

Natural Isotopes Trace Air, Age

A natural tracer for atmospheric processes and a new geological time scale are provided by beryllium-7 and chlorine-36, two cosmic-ray-produced radioisotopes recently uncovered. **Beryllium-7,** (half-life = 54 d) is formed in cosmic-ray stars at the top of the atmosphere. Its concentration at various levels of the atmosphere depends fairly critically on atmospheric processes since these have characteristic times comparable with the Be^7 half-life. Also production is latitude dependent, making north-south mixing important.

University of Chicago researchers J. R. Arnold and H. Al-Salih have observed Be^7 in concentrations of the order of 2 dpm/gal of rainwater. Based on a 1-meter annual rainfall the local Be^7 fall-out is 0.019 atoms/sec/cm^2. On the basis of certain assumptions as to the time for atmospheric mixing the production rate is computed to be 0.035 atoms/sec/cm^2. This fits the 0.015–0.06 atoms/sec/cm^2 estimated for the production rate in cosmic-ray stars. Despite the low production rate, Be^7 is the easiest cosmic-ray-produced nuclide to detect because it occurs substantially carrier-free. Beryllium-10 (2.5×10^6-yr half-life), also produced in cosmic-ray stars, is being sought.

Chlorine-36 (half-life = 308,000 yr) is produced by neutron capture in Cl^{35}. The specific activity in any rock sample will depend on how long it has been on the surface exposed to the full cosmic-ray neutron flux. This new tracer can provide a time scale for geological events 60,000–1,000,000 years ago.

Brookhaven researchers R. Davis, Jr., and O. A. Schaeffer have detected Cl^{36} with concentrations of the order of 0.12 ± 0.02 dpm/gm of Cl in certain phonolite rock samples from Cripple Creek, Colorado. This implies that the rock has been on the surface $24{,}000 \pm 4{,}000$ years. The saturation activity is calculated to be 2.3 dpm/gm of Cl. This is as high as it is in spite of the low abundance of Cl in the rock because the 43-barn capture cross section of Cl^{35} makes it a strong contender for cosmic-ray neutrons.

Russian Scintillation Track Chamber

A device for displaying the luminescent track of an ionizing particle in a scintillator has been revealed by Russian scientists Zavoiskii, *et al.* The work is published in *DAN SSSR* **100,** No. 2, 241 (1955), but the original experiments date back to 1952. Essentially the "luminescent chamber" consists of a CsI(Tl) crystal viewed by a lens that casts an image onto the photocathode of an image intensifier. The output image can be photographed or viewed directly.

If the device is monitored continuously, tracks can be seen to appear and disappear as the light output from ionizing events rises and decays. Greater effective signal-to-noise ratio can be achieved by using pulsed operation: the image intensifier is pulsed on only when an ionizing event occurs; then the background of thermal electrons from the photocathode is present only during the useful light pulse itself. Photographs of stars produced by fast neutrons show well-defined tracks in a 1-in. field of view. It is pointed out that the resolution time is limited mainly by the 10^{-14}-sec time of escape of photoelectrons from the cathode and that the device may therefore be useful in studying extra-fast luminescence properties.

Image-intensifier technology is well advanced in the U. S., but no one has built a luminescent chamber of this type. Some have considered it.

Neutron-Capture Therapy Using U^{235}

Encouraged by the success of B^{10} in neutron-capture therapy, researchers are inquiring into the suitability of U^{235}. If uranium exhibits a preference for tumorous tissue, then slow-neutron fission of U^{235} can provide a dense local source of ionization to destroy cancers. The applied radiobiology group at Oak Ridge National Laboratory has looked into the distribution and excretion of U in man as one of the preliminary studies required. Toxicology will need to be investigated also.

Historical note: in 1936, just two years after Fermi's original researches, G. L. Locher suggested neutron-capture therapy in a prophetic article on possible medical uses of neutrons (*Am. J. Roentgenol.* **36,** 1 (1936)).

NEWSMAKERS

Royale S. Foote has resigned as head of the geophysical exploration branch of the Atomic Energy Commission's raw materials division to form Resources Development Corp. The new company will have New York and Denver offices, and will offer consulting services in uranium exploration and mining and in radiation instrument development.

Bernard Kopelman has been named chief engineer of Sylvania Electric Products' atomic energy division. He formerly was manager of technical coordination for the division.

Henry Carroll has joined the Allis-Chalmers research division as a nuclear physicist.

Lewis M. Smith, president of Alabama Power Co., has been named chairman of the U. S. Chamber of Commerce's committee on commercial uses of atomic energy.

Morris D. Hooven of Public Service Electric and Gas Co., Newark, N. J., was elected president of the American Institute of Electrical Engineers last month.

David F. Shaw has been named assistant general manager for manufacturing by AEC. He formerly was manager of AEC's Hanford operations office. **James E. Travis** has been named acting manager at Hanford.

L. Roddis has been named deputy director of AEC's division of reactor development.

E. P. Blizard is serving as director of a newly established applied nuclear physics division at Oak Ridge National Laboratory. He formerly was associate director of the ORNL physics division. **A. Simon** will be associate director. The new division will be concerned with reactor physics.

Chauncey Starr has been named as a vice president of North American Aviation. He has directed the company's atomic energy research since it started. Now he will be in charge of a newly established nuclear engineering and manufacturing division.

C. Roger Sutton, former senior metallurgist at Argonne National Laboratory, has joined International Nickel Co.'s development and research division as a member of the stainless steel and heat resistant alloys section.

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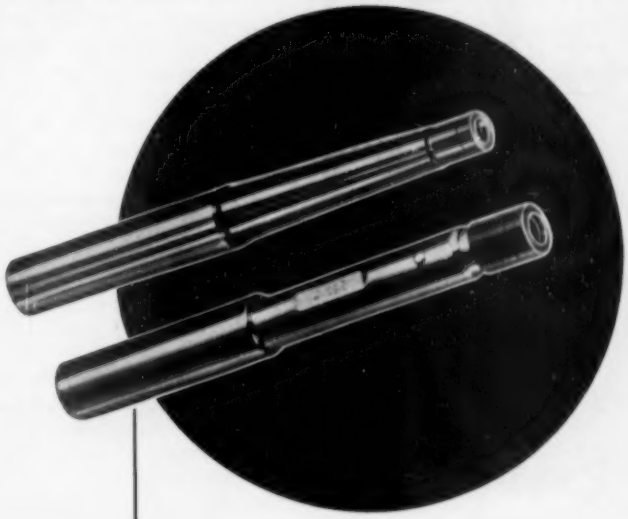

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LETTERS

Estimating Fe^{59}-Cr^{51} Mixtures

DEAR SIR:

To meet the needs of a hematological study in this Hospital, a method was developed to estimate Fe^{59} and Cr^{51} in the same blood sample. This work was done independently of, and apparently concurrently with, that reported by Hine *et al.* (NU, Feb. '55, p. 23). Although the methods are essentially the same, additional techniques of checking the validity of the procedure were employed in this laboratory.

Instrumentation and method. Samples (2 ml) were placed in a scintillation well counter whose output was fed into a linear amplifier (Atomic Instrument Co., Model 204-A). The discriminator output was counted with a decade scaler (Atomic Instrument Model 1020-A).

Counts from the mixture were produced by both Fe^{59} and Cr^{51} at the lower discriminator setting (16), and by Fe^{59} only at the higher setting (37). The observed counts, corrected for background, were used in the formula

$$A - B \times C = D$$

where A = cpm of Fe^{59}-Cr^{51} mixture at setting 16, B = cpm of mixture at setting 37, C = (Fe^{59} cpm, setting 16)/(Fe^{59} cpm, setting 37), and D = Cr^{51} cpm in mixture at setting 16; $A - D$ = Fe^{59} cpm in mixture at setting 16. Ratio C was determined on a sample of Fe^{59}, free of Cr^{51}.

A sample of U_3O_8 was used to adjust the counting rate to a constant value from day to day, thus permitting compensation for small variations in setting of gain and of high-voltage supply to the photomultiplier.

Possible interference by Fe^{55}. The Fe^{55} that is always present in pile-produced samples of Fe^{59} should not contribute to the Cr^{51} counts at setting 16, because the K-capture X-ray from Fe^{55} has an energy of only 70 kev, well below the 0.32-Mev γ-ray used for measuring Cr^{51}. This supposition was confirmed by counting a sample of Fe^{55}, prepared by neutron bombardment of iron enriched in Fe^{54} by electromagnetic separation. Even though the supplier (ORNL) reported that the sample contained very small quantities of Fe^{59} and Co^{60}, no counts were obtained from 0.01 μc Fe^{55}, which represents a 10% impurity in a 0.1-μc sample of Fe^{59}. The majority of Fe^{59} samples encountered in our blood studies contained 0.05 μc Fe^{59}, or less.

Recovery experiments. Accepting the assays furnished by the supplier (Abbott Laboratories), a dilution of each isotope was prepared containing 0.05 μc/ml. The table shows the mixtures of these two solutions that were counted to determine ability to recover the amounts known to be present therein. Sample 5, containing only Fe^{59}, was used to determine the ratio of Fe^{59} counts at settings 16 and

Recovery of Fe^{59} and Cr^{51} from Various Mixtures

			Fe^{59} solution				Cr^{51} solution			
Sample	Water (ml)	ml Cr / ml Fe	Volume (ml)	Observed (cpm)	Calculated (cpm)*	Obs. / calc.	Volume (ml)	Observed (cpm)	Calculated (cpm)†	Obs. / calc.
1	0.00						2.00	6,924	6,996	0.990
2	0.50						1.50	5,125	5,247	0.977
3	1.00						1.00	3,498	3,498	1.000
4	1.50						0.50	1,728	1,749	0.988
5	1.00		1.00	18,107	18,107	1.000				
6	0.00	7	0.25	4,341	4,527	0.959	1.75	6,075	6,122	0.992
7	0.00	3	0.50	8,631	9,054	0.953	1.50	5,275	5,247	1.005
8	0.00	1	1.00	18,059	18,107	0.997	1.00	3,320	3,498	0.949
9	0.25	0.75	1.00	18,039	18,107	0.996	0.75	2,446	2,624	0.932
10	0.50	0.50	1.00	17,880	18,107	0.987	0.50	1,725	1,749	0.986

* Counts observed for sample 5 × volume in ml.
† Counts observed for sample 3 × volume in ml.

37 on the pulse discriminator. The ratio was 1.66.

Reliability of counting data. The 0.95 error of the net counting rates in the table was ±1.00% or less, except for samples 3 and 4, which were ±1.11 and ±1.16%, respectively. Based upon the calculated errors for sample 5 (Fe^{59} only), the error of the ratio (Fe^{59} at 16)/(Fe^{59} at 37) was ±1.26%, or its precision was 1.66 ± 0.02. This degree of uncertainty was reflected in the values of the Fe^{59} and Cr^{51} counting rates calculated with the equation stated earlier.

The Fe^{59} and Cr^{51} concentrations in blood samples frequently fall to rather low levels, especially when blood is withdrawn a month or more after the initial administration. Under these circumstances, it may become necessary to sacrifice accuracy to save counting time. By counting specimens for a maximum of 1 hr, however, we have been able to estimate the counting rates with sufficient precision to permit satisfactory conclusions in the physiological experiments.

—S. Allan Lough and
George J. Hertsch
Physics Laboratory
Francis Delafield Hospital
New York, N. Y.

Correction

Dear Sir:

You will be sorry to hear that "Nomogram for Nuclear Reaction Calculations" (NU, Oct. '54, p. 56) contained a serious error in that the nomogram as printed was completely inaccurate and, therefore, useless.

For example, a line drawn through (ϕ = 90 deg, θ = 90 deg) should intersect the third scale at K = 1, and the fourth scale at I = 1. The diagram gives K = 0.85 and I = 0.9, roughly (off scale). The line through (θ = 90 deg, K = 1) gives I = 1.4 instead of 1.0, and so on.

The errors arise primarily because the spacing of the scales has been altered. Spacing should be in the ratio 1:1:2, but measured spacings are 5.0, 5.3, and 9.3 cm.

—F. J. M. Farley
United Kingdom Atomic Energy Authority
Atomic Energy Research Establishment
Harwell, Nr. Didcot
Berkshire, England

[Editor's Note: *Regrettably, although the scales of the nomogram are of the correct dimensions, the spacing between the scales was altered. Upon request, we shall provide corrected copies.*]

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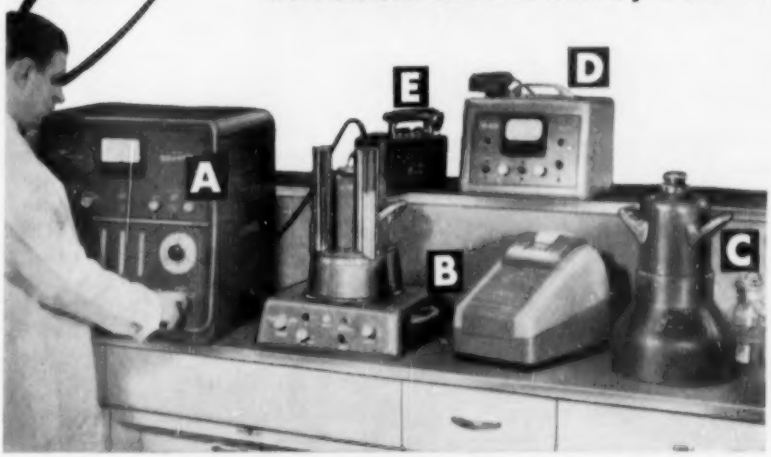

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BOOKS

Rare Metals Handbook

Edited by CLIFFORD A. HAMPEL (Reinhold Publishing Corp., New York, 1954, xiii + 657 pages, $12.00). Reviewed by R. J. TEITEL, Brookhaven National Laboratory, Upton, N. Y.

This book summarizes the available data on some 34 rare or uncommon metals. It has a three-fold objective: (1) to bring together the available reference data on the rare metals; (2) to offer an authoritative, concise and readily available background to the man who desires information about a specific metal and, at the same time, to give him selected references; (3) to provide a convenient source of data for the man who has a general question, such as "What metals have melting points over 1,000° C and densities below that of steel?"

An expert familiar with each of the metals was called upon to write each chapter in the book. The metallic state was emphasized in the discussion of each metal or group of similar metals. Typical subjects covered in each chapter are mechanical, physical, and chemical properties; availability; preparation; cost; metallography; fabrication; alloy and commercial importance.

The metals described in the book are the alkaline earths (calcium, barium, and strontium), beryllium, bismuth, boron, cadmium, cobalt, gallium, germanium, hafnium, indium, lithium, manganese, molybdenum, the platinum metals (ruthenium, rhodium, palladium, osmium, iridium and platinum), the rare-earth metals (lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium and yttrium), rhenium, selenium, silicon, tantalum, columbium, tellurium, thallium, thorium, titanium, tungsten, uranium, vanadium and zirconium.

Chapter 1, *The Rare Metals*, discusses the choice of book title and the scope of the book. The so-called rare or uncommon metals are those metals that were considered little more than scientific curiosities before the last war and are now receiving increased attention. In the course of the discussion, the natural resources for the various rare metals and new methods devised for their extraction are compared to those for the common metals.

Chapters 2 through 28 are devoted to the presentation of the data on each of the metals mentioned above.

The last chapter, *Physical Properties of Metals*, summarizes the specific properties of the rare metals as well as the common metals. Several of the data, such as density, melting point, thermal-neutron-absorption cross section, and current prices, are arranged in tables in ascending order of the property or price.

The author and the contributors are to be congratulated on their collection of so much data into 657 pages. They have gained the 3 objectives set forth in the introductory passages. The reference list for each metal is not complete or up to date, but sufficient for objective 2. This book should be a handy compliment to the "Metals Handbook," which covers the more common metals.

The Bomb, Survival, and You

By F. N. SEVERUD and A. F. MERRILL (Reinhold Publishing Corp., New York, 1954, 264 pages, $5.95). Reviewed by RALPH E. LAPP, Nuclear Science Service, Arlington, Va.

Significance should be given to this book on atomic defense for two reasons. First, it is authored by a recognized professional architect, thus highlighting emphasis upon the virgin field of structural design in the Age of the Megaton. Second, the book stresses organic reduction of target vulnerability by making individual plants more resistant to the primary effects of nuclear weapons. The latter is important since so much attention has focused principally upon the theme "space is our ally."

Serious students of industrial planning for survival against the threat of modern war are now agreed that industrial dispersion has up to now been a two-dimensional problem. Emphasis has been placed (although few have followed the doctor's orders) on plant location. The object has been to prevent too great a concentration of critical industrial facilities in a given area. By and large, the distance between critical facilities has been the object of study. Now if we follow the advice of the authors, we will add a third dimension to defense planning in the form of structural resistance to blast and heat from nuclear explosives. This is highly sensible advice. It permits a degree of flexibility in plant location so that if a manufacturer of jet-engine parts wants to make his plant less vulnerable to attack he can employ both the principle of physical site location and structural strength. For example, if the plant should be located 15 miles from a certain point considering normal plant construction, it may be possible to trim this distance down by reliance upon protective-resistant construction.

The authors divide their study into two parts. The first is a qualitative description of protective construction, and the second is a technical supplement, which is published separately and which this reviewer has yet to see. [See editor's note at end of review.] For this reason it is difficult to provide a real assessment of the book since many of the author's assumptions are undoubtedly buried in the supplement. It is clear, however, that the authors have concentrated their attention upon the primary blast-heat effects of nuclear bombs. Had they known about the immense importance of secondary radioactive fallout, they undoubtedly would have revised much of their thinking about protective construction. This does not mean that their work is not valid, but it clearly follows that it must be supplemented.

In guessing at how the authors might revise their book in the light of fallout, the reviewer believes that they would give serious consideration to underground construction. Architectural design now permits subterranean building and removes many of the old stigma attached to "going underground." There is no reason, for example, why plants can not be built flush-to-the-surface with employee parking lots directly over the assembly line. Anyone who has glanced out of the window of an airplane approaching a city, notices that very often the space devoted to parking areas is half of the plant real estate. Thus the new construction technique could cut costs as well as car-to-bench time.

Judged as literature, the book is weakly organized and suffers from a rather tiresome editorial overtone akin to "Why doesn't somebody do something?" This should not, however, detract from the pioneer nature of the attempt to get architects and businessmen interested in nonmilitary defense measures. Our Federal Government has mildly advocated a "Won't you please?" form of industrial protection,

but has shrunk from even appearing to sponsor a get-tough policy. Thus it would appear that if our industries are to know any measure of nonmilitary defense, it will have to result from private initiative. Should this book prove a stimulus to such private enterprise, it will be a real contribution to our nation's security.

[*EDITOR'S NOTE: Since receiving Dr. Lapps' review, we have received the supplement he refers to ("The Bomb, Survival, and You—Technical Supplement," 45 pages, $2.50). The supplement provides a mathematical analysis of blast loadings, prepared by Kurt Bernhard, I. Voshinin, and R. Calgi. Radioactive fallout is not discussed.*

Under ordinary conditions, loading is treated as a static quantity, with no need to consider the acceleration or inertia of a structural member. However, a member subjected to blast undergoes almost instantaneous loading and its mass is a main source of resistance. These considerations are applied to a fixed-end, one-way-reinforced concrete slab.

The authors believe that, with the information given here, the engineer can develop his own design procedure.]

Nuclear Geology

Edited by HENRY FAUL (John Wiley & Sons, Inc., New York, 1954, xvii + 414 pages, $7.00). Reviewed by L. THOMAS ALDRICH, Department of Terrestial Magnetism, Carnegie Institution of Washington, Washington 15, D. C.

This collection of articles by 26 authors, including the editor, is a worthwhile attempt to collect in one book the physical and geological techniques, data, and concepts required to understand nuclear phenomena as found in and applied to geological settings. To be sure the physicist will not learn much physics from this volume and may even be somewhat amused by the form of presentation. By the same token, I would presume there to be little new in the geological data and concepts presented. For both groups working in this field there will be, however, something of interest in the other specialty.

The subject matter in this symposium ranges from the application of instruments and techniques of nuclear physics to measurements of geological interest through the geochemistry of the commonly occurring radioactive elements, U, Th, Rb, and K, to the origin of the earth. With this as the scope of the volume, the need for an

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adequate bibliography is apparent. For the parts of the book familiar to me, this is available.

A good review of the various physical methods of analysis applicable to geological samples, including counting, nuclear emulsion, and mass spectrometric techniques, is found in Chapter 1. Other subjects discussed by chapters include the occurrence of U and Th in igneous, volcanic and sedimentary rocks, the abundance of potassium, rare gases and natural fission, radioactive heat in the earth, radiation damage and energy storage in crystalline rocks, the formation of hydrocarbons as an effect of radioactivity and petroleum genesis, nuclear methods in geophysical prospecting, and the origin of the earth.

One of the longer chapters in this book is that on the determination of absolute ages of minerals. In it a number of mineral ages are presented that have been collected from a variety of sources, many of them as yet unpublished. The fact that so many of the results are unpublished, coupled with the uncritical presentation of so many divergent results for the same pegmatite, for instance, will limit the usefulness of this table for those uninitiated in the problems of such measurements. For those in the field, however, it is a very helpful table to have available. The problems of age measurement by methods related to each of the naturally radioactive elements U, Th, Rb, K and C are discussed in varying detail. Those on the K^{40}-A^{40} system and the venerable but frustrating U-He method are particularly complete.

"Nuclear Geology" is recommended reading for all who are (1) curious as to the number of nuclear phenomena that leave their record in the rocks, and (2) using this kind of data from rocks, in interpreting the past history of the earth.

Elementary Theory of Nuclear Shell Structure

By MARIA GOEPPERT MAYER and J. HANS D. JENSEN (John Wiley & Sons, Inc., New York, 1955, xiv + 269 pages, $7.75). Reviewed by L. C. BIEDENHARN, The Rice Institute, Houston, Texas.

Nuclear configurations characterized by certain proton and neutron numbers (the "magic numbers") exhibit particularly great stability, and from the earliest days of nuclear physics when these data began to emerge, an interpretation of nuclear structure in terms of a "shell" model was attempted, the completion of a shell being indicated by enhanced stability. Such considerations did not gain universal acceptance —largely the result of meager evidence, but in no small part the result of theoretical difficulties in justifying such a model. These latter difficulties are still very much with us, but since 1948 when Mrs. Mayer presented anew the evidence for the magic numbers, and 1949 when Mayer and, independently, Haxel, Jensen, and Suess interpreted the magic numbers by a shell theory with spin-orbit coupling, acceptance of the shell model has been virtually a necessity.

The present book is an elementary and self-contained yet complete exposition of the literature on shell theory, and a detailed examination of experimental data by means of this theory. The aim throughout has been to systematize and to correlate the data, and in so doing to give valuable insights into nuclear structure. Although the authors are at pains to present limitations of the theory, the view emerges that the model is remarkably successful and probably the real question, as put by Feenberg, is, why does the shell theory work so well? The authors' point of view is, however, deliberately heuristic, and as such in the best tradition. After all, useful working concepts of valence long preceded quantum mechanical justification.

The plan of the book is as follows: After a brief introductory discussion of stable nuclei, the empirical evidence for the magic numbers is discussed. Since the nuclear shell theory is patterned after the electronic structure of atoms, a chapter summarizing the relevant features of atomic structure is included. The discussion of the nuclear shell theory proper is given in the next two chapters. The remaining eight chapters are devoted to the examination and elucidation of the model in reference to specific nuclear features: nuclear spins and magnetic moments, parity, quadrupole moments, beta decay, nuclear spectroscopy, and isomerism. Light nuclei, nuclei of even and odd A are discussed in detail. The data are summarized in numerous tables and curves.

The book is addressed to "physicists and chemists whose daily work concerns the nucleus," and the presentation involves a minimum of technical details. Appendices treat the more mathematical topics such as angular momentum, coupling of identical and nonidentical nucleons, and multipole radiation.

The authors have succeeded in their purpose extremely well. They bring together and systematize an amazing amount of experimental material which is a tribute both to their abilities and the power of their model. Their presentation is clear and direct. The book is marred by a somewhat haphazard attitude toward references to the literature, and there are a few too many misprints (all trivial, however)—yet these are but very minor annoyances in a thoroughly commendable, useful, and valuable book.

BOOKS RECEIVED

Fundamentals of Radiobiology, by Z. M. Bacq and Peter Alexander (Academic Press, Inc., New York, 1955, xii + 389 pages, $6.50). (*To be reviewed.*)

Autoradiography in Biology and Medicine, by George A. Boyd (Academic Press, Inc., New York, 1955, xiii + 399 pages, $8.80). (*To be reviewed.*)

Recurrent Electrical Transients, by L. W. Von Tersch and A. W. Swago (Prentice-Hall, Inc., New York, 1955, ix + 399 pages, $10.35). (*To be reviewed.*)

Servomechanisms in Regulating System Design, vol. 2, by Harold Chestnut and Robert W. Mayer (John Wiley & Sons, Inc., New York, 1955, xiii + 384 pages, $8.50). (*To be reviewed.*)

Analysis of Feedback Control Systems, by Robert A. Bruns and Robert M. Saunders (McGraw-Hill Book Co., Inc., New York, 1955, xv + 383 pages, $7.50). (*To be reviewed.*)

Introduction to Physics, by Frank M. Durbin (Prentice-Hall, Inc., New York, 1955, xiv + 780 pages, $9.00). This book is intended for the liberal-arts student; a knowledge of trigonometry is not necessary.

Advances in Electronics and Electron Physics, Vol. 6, edited by L. Marton (Academic Press, Inc., New York, 1955, xi + 538 pages, $11.80). Formerly known as "Advances in Electronics," the new title is believed to better describe the subject matter. The topics include: metallic conduction, relaxation processes in ferromagnetism, ferrites, space-charge-limited

currents, semiconductors, electron microscope, traveling-wave tubes, and paramagnetism.

Théories Relativistes de la Gravitation et de l'Électromagnétisme, by A. Lichnerowicz (Masson et Cie., Paris, 1955, xii + 298 pages, $8.00). Assuming only a knowledge of the elements of tensorial calculus, this book aims to give a mathematically explicit picture of general relativity and the unitized theory and to show in what sense they are derived from the classic theories of potential and hydrodynamics and the theories of wave propagation.

An Outline of Atomic Physics, 3rd ed., by Oswald H. Blackwood, Thomas H. Osgood, and Arthur E. Ruark (John Wiley & Sons, Inc., New York, 1955, x + 501 pages, $7.50). One-third of this edition of a book first published in 1933 is new material, and the remainder has been almost entirely rewritten. Intended for readers with only an introductory knowledge of physics, the first ten chapters include most of the material of previous editions. Chapters 11–14 discuss nuclear and radiation properties. The last chapter provides a simplified account of the theory of relativity.

Ionography: Electrophoresis in Stabilized Media, by Hugh J. McDonald (Year Book publishers, Inc., Chicago, 1955, x + 268 pages, $6.50). Ionography is a relatively new technique for determining electrophoretic mobilities and making absolute separations and identifications of microamounts of high-molecular-weight substances that are difficult to separate by chromatography. Although stabilizing media such as agar, starch, and glass-fiber ribbon can be used, this book emphasizes horizontal paper strips. After describing the method and apparatus, the authors discuss various applications to organic and inorganic substances. The bibliography lists 865 foreign and domestic papers.

Radiobiology Symposium, 1954, edited by Z. M. Bacq and Peter Alexander (Academic Press, Inc., New York, 1955, xix + 362 pages, $9.80). This book contains 50 papers and their discussion from the Liége conference, September, 1954 (NU, Dec. 1954, p. 42); 12 of the papers are in French.

Networks, Lines, and Fields, 2nd ed., by John D. Ryder (Prentice-Hall, Inc., New York, 1955, xi + 593, $7.65). Written for the undergraduate student,

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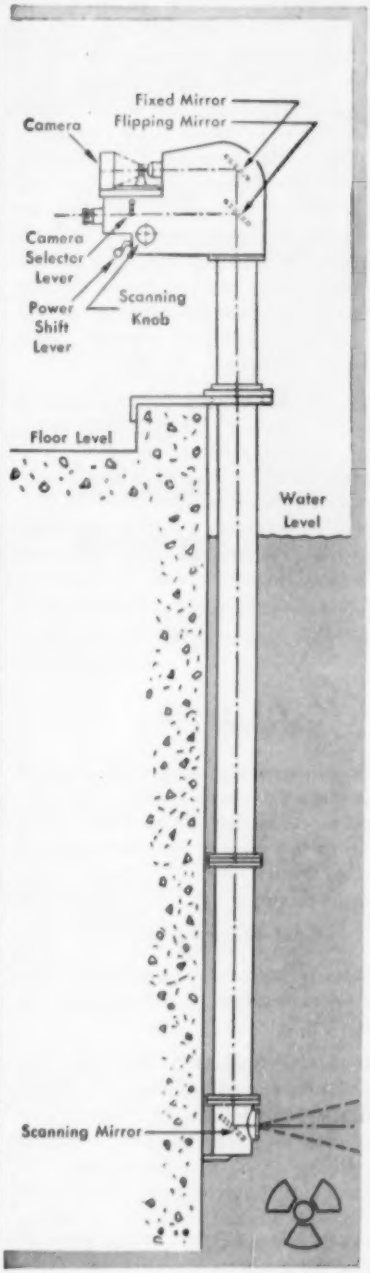

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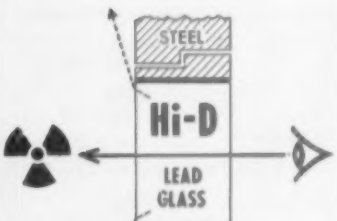

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this book has been extended with new chapters on the line used at power frequencies, Foster's reactance theorem and canonic networks, determination of polyphase-line parameters, and basic antenna theory.

Almost Periodic Functions, by A. S. Besicovitch (Dover Publications, Inc., New York, 1955, xiii + 180 pages, clothbound—$3.50, paperbound—$1.75). This reissued book sums up the theory of almost periodic functions as created by Bohr, expressed by Poussin, and generalized by Stepanoff, Wiener, Weyl, Bohr, and others. The chapters are *Uniformly Almost Periodic Functions, Generalisation of Almost Periodic Functions,* and *Analytic Almost Periodic Functions.*

The Continuum and Other Types of Serial Order, by Edward V. Huntington (Dover Publications, Inc., New York, 1955, vii + 82 pages, clothbound—$2.75, paperbound—$1.00). A reissue of the 2nd edition, published in 1917, this book gives "a systematic elementary account of the modern theory of the continuum as a type of serial order. . . . "

ALSO OF NOTE

Experiments in the Computation of Conformal Maps. This 61-page monograph is edited by John Todd for the National Bureau of Standards Applied Mathematics Series 42. Three experiments carried out at NBS are described and evaluated (desk calculation, punched-card equipment, and NBS Eastern Automatic Computer). *Government Printing Office, Washington 25, D. C., $.40.*

Biennial Report 1953 and 1954; National Bureau of Standards. Miscellaneous Publication 213, 162 pages, summarizes research and development activities of NBS in the physical sciences during fiscal '53 and '54. *Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., $.60.*

The Gyroscope Applied, by K. I. T. Richardson (Philosophical Library, Inc., New York, 1954, 384 pages, $15.00). Based on "The Gyroscope and Its Applications," published in 1946, this book is almost entirely rewritten. The mathematics are collected in an appendix. It covers applications from aircraft instruments to oceanliner-roll stabilizers.

Radiation and Monitoring Fundamentals for the Fire Service. The original report (1952) and this current revision were written by the International Association of Fire Chiefs Committee on Radiological Hazards in Fire Fighting under the chairmanship of M. M. Braidech, research director of the National Board of Fire Underwriters. The radioactive-fallout hazard outside the target area, elementary atomic physics, nuclear-explosion effects, detection instrumentation, decontamination, and safeguards against contamination are discussed. *International Association of Fire Chiefs, Hotel Martinique, 32nd and Broadway, New York 1, N. Y., $1.00.*

Statistical Aspects of the Nucleus, BNL 331. This volume contains the complete tape-recorded proceedings of a conference held January 24–26 at Brookhaven National Laboratory. Attending the conference were many of the theoreticians and experimentalists active in the determination of nuclear properties and their interpretation in terms of statistical models of the nucleus. All aspects of the subject were covered. Sessions included Low-Energy Scattering, with E. P. Wigner as chairman and E. Vogt and R. G. Thomas as speakers; Elastic Scattering, with K. M. Watson chairman and D. S. Saxon speaker; Inelastic Scattering and Reactions I (Residual Nuclei in Discrete States), with L. Wolfenstein chairman and H. Feshbach and H. McManus speakers; Inelastic Scattering and Reactions II (Residual Nucleii in Continuum States) with V. F. Weisskopf as chairman and P. C. Pugelot as speaker. A recapitulation of the conference by Weisskopf is also included. A very valuable feature of this report is the inclusion of the discussion that followed the papers; this actually occupies most of the pages and is as instructive as the papers themselves. *Office of Technical Services, Department of Commerce, Washington 25, D. C., $.80.*

Selling to AEC. This publication supersedes the 1953 issue. Included are organization and purchasing program, directory of purchasing offices, and list of products purchased. *Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., $.25.*

Computer Development (SEAC and DYSEAC) at the National Bureau of Standards. This 146-page publica-

tion (NBS Circular 551) presents the more important engineering aspects of the Bureau's electronic computer program, based largely on experience with its Eastern Automatic Computers (SEAC and DYSEAC). *Government Printing Office, Washington 25, D. C., $2.00.*

Nuclear Power Reactors, Vol. 2. This nuclear power study team report by Foster Wheeler Corp. and Pioneer Service and Engineering Co. was submitted to the U. S. Atomic Energy Commission in Oct. '53. It presents economic surveys of plants using solid-fuel thermal converters, fluid-fuel thermal breeders, and fast convertors and breeders. Since this report is unclassified, it does not contain detailed results of the survey. *Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., $.15.*

Bibliography and Index on Dynamic Pressure Measurement. NBS Circular 558, 124 pages, compiled by W. G. Brombache and T. W. Lashof, contains references on dynamic pressure measurement and related subjects. *Government Printing Office, Washington 25, D. C., $.75.*

Shell Theory of the Nucleus. This 224-page monograph, by Eugene Feenberg, is the third in the "Investigations in Physics" series of the Princeton University Press, edited by E. Wigner and R. Hofstadter. The author describes the development phase of nuclear shell theory wherein shell models were formulated and used to interpret spins and parities, magnetic dipole and electric quadrupole moments, isomerism, and beta decay. *Princeton University Press, Princeton, N. J., $4.00.*

Uranium Official Yearbook. This 80-page booklet covers all aspects of uranium prospecting: types of minerals, detection instruments, prospecting techniques, assaying, staking a claim, and selling uranium. *New Science Institute, 5204 Santa Monica Blvd., Los Angeles 29, Calif., $2.00.*

Organic Syntheses, Vol. 3. Edited by E. C. Horning, this 890-page collective volume encompasses all material in annual volumes 20–29, revised and brought up to date. *John Wiley & Sons, Inc., 440 Fourth Ave., New York 16, N. Y., $15.00.*

The National Research Council Review, 1954 (Canada). This review

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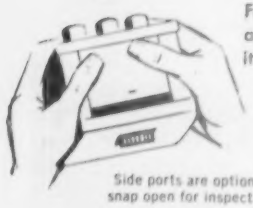

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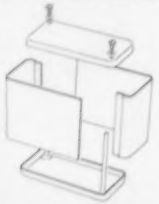

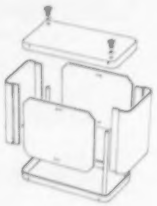

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chiefly describes the work in the year ending Dec., 1953, and includes some later work. Also included are reports of divisions and committees and details of university research grants. *Public Relations Branch, National Research Council, Ottawa, Canada, $.75.*

The Thyroid. This is a report of the 7th annual symposium, June 9–11, 1954, of the Biology Dept. of Brookhaven National Laboratory. Subjects covered are phylogenetic and developmental aspects; pituitary regulation; iodide-concentrating mechanism; antithyroid compounds; circulating thyroid hormone; effect of hormones on enzyme systems; distribution, conjugation, and excretion of hormone; interrelation of thyroid and adrenals; spontaneous hyperplasia and neoplasia; experimental thyroid tumors; I^{131} concentration and thyroid morphology; and relation of thyroidal activity and radiation to growth of hypophyseal tumors. *Office of Technical Services, Department of Commerce, Washington 25, D. C., $1.75.*

The Chemical Industry Facts Book. This 148-page 2nd edition of the "Facts Book" contains sections on Growth of the Chemical Industry, How the Chemical Industry Operates, and Chemicals in Everyday Life. *Manufacturing Chemists' Association, Inc., Cafritz Building, 1625 Eye St., N. W., Washington 6, D. C., $1.00.*

Nuclear Levels in the Neighbourhood of $1F_{7/2}$ State. This 78-page monograph by R. H. Nussbaum discusses nuclear-energy-level systematics, particularly for $1f_{7/2}$ states. Experimental determination of levels by means of gamma-ray transitions are reported for the daughters of Ti^{45}, Sc^{43}, Cr^{49}, Cr^{51}, Ti^{51}, V^{47}, Fe^{55}, and Sc^{49}. *Van Gorcum & Comp. N.V., Uitgevers, Assen, Netherlands, $2.08.*

Biochemical Aspects of Basic Mechanisms in Radiobiology. This is the report of the fourth (1954) in a series of conferences sponsored by the Academy-Research Council Subcommittee on Radiobiology of the Committee on Nuclear Science. *Publications Office, National Academy of Sciences and National Research Council, 2101 Constitution Ave., Washington 25, D. C., $1.50.*

Standard X-Ray Diffraction Powder Patterns. Circular 539, by H. E. Swanson, R. K. Fuyat, and G. M. Ugrinic, presents 49 patterns for the

identification of unknown crystalline materials based on the three strongest reflections of each material. A comparison is made between all powder diffraction data available for each of the substances. *Government Printing Office, Washington 25, D. C., $.45.*

Electronics Test Equipment Data Sheets. This 2,300-page, 3-volume set covers almost 900 separate test equipments of special interest to the U. S. Air Force. *Carl L. Frederick & Associates, 4630 Montgomery Ave., Bethesda 14, Md., $100.*

CP-5 Brochure (ANL-5362). This brochure consists of a detailed description of the CP-5 reactor by J. T. Weills, a cost summary, 25 photographs taken during construction, 75 drawings of the reactor, and 6 drawings of the building housing the reactor. *Argonne National Laboratory, Box 299, Lemont, Ill., $75.00.*

Tables of Sines and Cosines for Radian Arguments. This publication in the National Bureau of Standards Applied Mathematics Series 43 is an extended and corrected reissue. The main table is extended to $x = 25.2$; the table of values of $p(1 - p)$ is replaced by $\frac{1}{2}p(1 - p)$. *Government Printing Office, Washington 25, D. C., $3.00.*

Consulting Services. The 15th edition of this directory contains three sections: (a) alphabetical listing of fields with members specializing or qualifying in them; (b) description of members' qualifications and activities; (c) alphabetical and geographical listing of members. *Association of Consulting Chemists and Chemical Engineers, Inc., 50 E. 41st St., New York 17, N. Y., $1.00.*

Atomic Energy Research at Harwell. This report describes the work done at Harwell since 1951 up to the formation of the United Kingdom Atomic Energy Authority in August, 1954. Some earlier work is also described that has been declassified since issuance of the previous report ("Harwell—the British Atomic Energy Research Establishment, 1946–1951"). The first section includes discussions of advances in the production, reactor, and isotope programs. The second section describes fundamental research in physics, chemistry, chemical engineering, and metallurgy. *Butterworths Publications Ltd., 88 Kingsway, London, W.C.2, England, 5 shillings.*

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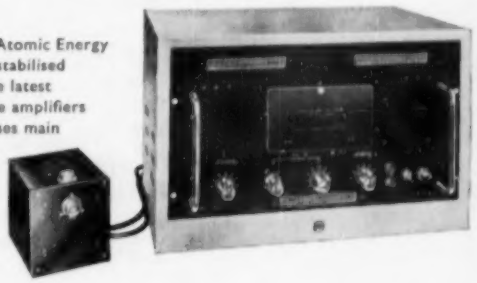

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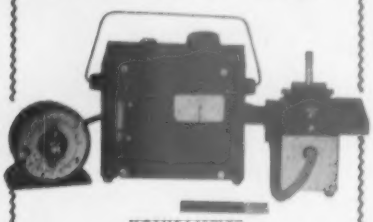

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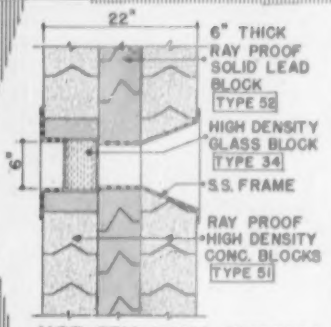

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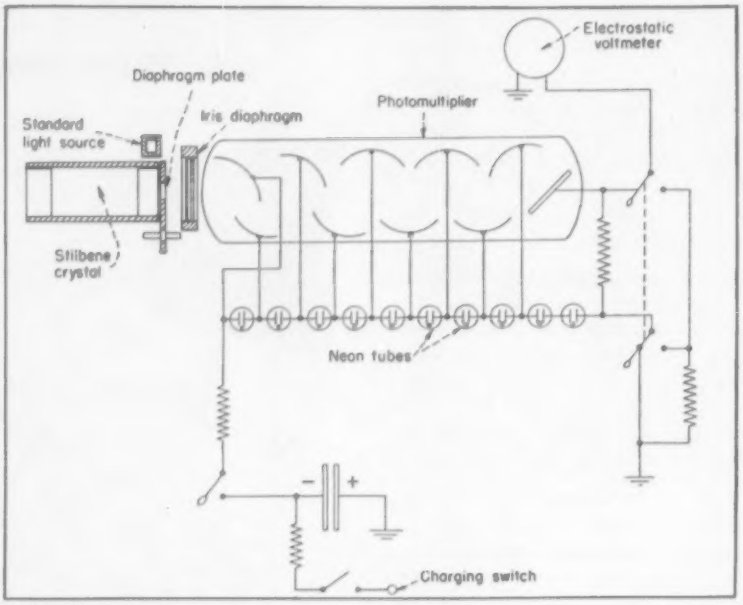

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Two Gamma-Ray Survey Meters

New types of gamma-ray survey meters are described in U. S. 2,700,108 and 2,700,110, issued to Morris H. Shamos and assigned to Chatham Electronics Corp.

The first patent describes a portable, lightweight, direct-reading instrument that covers the range between 10 mr/hr and 500 r/hr. No batteries are required nor any form of electrical generator during the operating period; the power is supplied by a charged capacitor. As shown in the illustration, a metal cylinder containing a stilbene crystal is aimed at the radiation source. A photomultiplier tube, e.g., 931A or 1P21, is mounted close to the rotatable diaphragm plate containing various size holes and an iris diaphragm so that the light generated in the crystal shines on the photocathode. A series of neon tubes provide equal voltage steps for the secondary electrodes. The reading is made on an electrostatic voltmeter. Switches are provided for charging the capacitor and for connecting the capacitor to the photomultiplier when a reading is to be taken. A small quantity of fluorescent material in a box having a removable cover acts as a standard light source for calibrating.

The second survey meter utilizes two ion chambers in series, one to measure the radiation field and the other a constant-current unit having a built-in ionization source, e.g., radium. A voltage indicator, e.g., an uncalibrated gold-leaf electroscope, is connected across the first chamber. A mechanically operated, calibrated shield is adjusted over the radium source until a sharp voltage change is shown by the electroscope, indicating the radiation level. The chambers are connected to a charged capacitor.

Reducing Background of Gamma-Ray Counters

U. S. 2,701,175, issued to Roy P. Mazzagatti, O. D. Stephens, and Archie S. Conners, and assigned to The Texas Co., discloses a method of treating gamma-ray counters to reduce their spurious counting rate.

After the normal procedure for cleaning and fabricating a gamma-ray counter, the gaseous filling is removed from the counter housing and its interior is subjected to a vacuum of less than one micron for 1½–2½ hr.

During this time, an alternating potential of 6,000–8,000 volts at 60 cycles/sec is impressed on the anode and cathode of the counter. According to the inventors, the counter should then be substantially free of spurious counts.

Radiation Dosimeter

An inexpensive, simply operated dosimeter is described by George A. Argabrite in U. S. 2,700,109 (assigned to Pacific Transducer Corp.).

A Pyrex container contains a large number of polystyrene spheres of 1-mm diameter. When the dosimeter is in the discharged condition, the spheres are at the bottom of the container. By shaking the container vigorously, some of the spheres align themselves along the wall because of electrostatic attraction. The upper surface of the spheres then has the appearance of a meniscus. After 50 or 60 shakings, a "saturation" condition sets in, so that further shaking has no effect, nor does inverting the container change the number of spheres clinging to the wall.

Exposure to ionizing radiation, however, causes some of the spheres to fall to the bottom of the container. The number of spheres discharged is proportional to the amount of radiation exposure. Ambient temperature and pressure have no effect.

Gamma-Ray Measurement

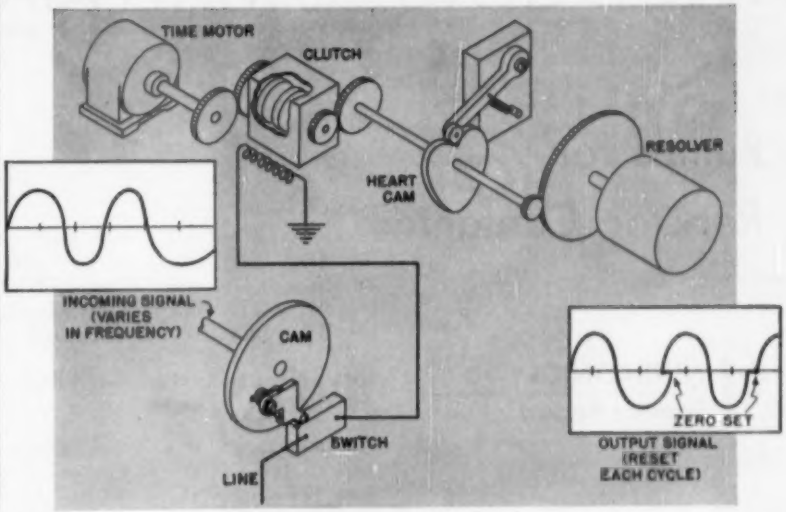
If several γ-ray counters are electrically connected in parallel, the sum of the counts is less than the sum of the counts when they are operated separately due to the increase in electrical capacity across the parallel counters. This increases the recovery time after each count.

As described in U. S. 2,701,312 (assigned to The Texas Co.), Arthur H. Lord, Jr., avoids this difficulty by using a separate quenching circuit and a separate preamplifier or pulse equalizer for each counter. The outputs of all the preamplifiers are then electronically mixed, the output of the mixer being recorded on a single record. According to the inventor, the only losses then occurring are due to coincidence counts, which are considered negligible.

* * *

These descriptions are based on abstracts furnished by Melvin Nord, Registered Professional Engineer and Patent Attorney, Detroit, Mich.

SINCE 1915 LEADERS IN AUTOMATIC CONTROL



HOW TO ZERO-SET RANDOM PHASE VARIATIONS

Many modern control devices are designed for applications where sensed input signals fluctuate randomly about an approximately known frequency. In some of these applications, the information is conveyed by the phase relationship within one cycle, and the random cycle-to-cycle phase variations often submerge the signal in noise. Filtering, or averaging, techniques may be extremely difficult to devise because of the requirement for use within one cycle.

The ingenious electro-mechanical solution shown above is a typical Ford answer to a difficult problem. It is rugged and reliable, yet compact and easy to service. In operation, a constant-speed motor drives a resolver at the required speed. The sensed input controls the operation of the clutch, and at each zero-crossing in the positive direction, decouples the motor from the line. At the same time, the spring-loaded heart cam follower resets the synchro shaft to its zero position.

In this manner, the resolver is reset to a prescribed phase relative to the signal at a fixed point of every cycle of the generated signal.

This is another instance of how Ford's engineering staff selects the most efficient device to solve a problem. Here at Ford mechanical *and* electronic devices are given consideration in solving any problem.

Since 1915 the engineers at Ford Instrument Company have specialized in such equipment as computers, controls, and servo-mechanisms in hydraulics, electronics, mechanics and magnetics for the Armed Forces and for industry. If you have problems in any of these fields, it will pay you to discuss them with Ford engineers.

67

FORD INSTRUMENT COMPANY
DIVISION OF SPERRY RAND CORPORATION
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ENGINEERS
of unusual abilities can find a future at FORD INSTRUMENT COMPANY. Write for information.

PRODUCTS AND MATERIALS

Mechanical Pumps

Pumps for Reactor Coolants

A NUCLEONICS Special Report

THIS TABULATION of pumps for liquid nuclear-reactor coolants is the result of a NUCLEONICS survey of pump manufacturers. The pumps listed are special, being designed for leakproof operation and/or the pumping of liquid metals (*1–4*). The tabulation is in two parts, covering mechanical pumps and electromagnetic pumps. The former move the liquid by exerting direct mechanical forces on it, while the latter exert force electromagnetically and thus can only pump electrically conducting liquids (i.e., liquid metals).

In both categories special steps have been taken to reduce leakage of the pumped liquid to near zero. Electromagnetic pumps are built completely enclosed since there are no moving parts to seal. Canned-rotor mechanical pumps have their moving parts, and rotor of the motor that drives them, hermetically sealed. The magnetic fields that move the rotor pass through a thin liner or liners between the rotor and stator. Canned-motor pumps have the entire motor in the pumped fluid, with protection afforded the stator and rotor windings (e.g., with liners). Another type, the gas-sealed centrifugal pump, has the usual type of seal, but the pumped fluid is kept from it by a layer of pressurized gas so that only gas can leak. Westinghouse's tank type has the motor filled with pressurized gas.

Each reactor application will differ in its pump requirements; the manu-

Supplier's address	*Model*	*Type of pump—hp*	*Cost ($)*	*Approximate dimensions*			
				Ht. (in.)	*Width (in.)*	*Length (in.)*	*Wt. (lb)*
Allis-Chalmers, Box 512, Milwaukee, Wisconsin	APD	Canned motor		10	10	10	75
	LAPD	Canned motor		75	30		15,000
	HAPD	Centrifugal					
Buffalo Pumps, Inc., N. Tonawanda, N. Y.	4LIQ	Vert. centrif.	15,000	120	52		3,700
Chempump Corp. 1300 E. Mermaid Lane, Philadelphia 18, Pennsylvania	E	Canned rotor—⅙	200	8	6	7	
	CF	Canned rotor—¾	600	9	8	11	
	C	Canned rotor—3	900	13	11	15	
	CHS	Canned rotor—5	1,500	16	11	19	
	CFH	Canned rotor—1.5	800	15	9	13	
Fostoria Pressed Steel Corp., Fostoria, Ohio	P3100	Canned rotor—⅛	175	6	6	10	25
General Electric Co., Atomic Pwr. Eqpt. Dept., Schenectady, N. Y.	CM	Canned motor—1.5		18	18	36	200
Reliance Electric & Eng., 1068 Ivanhoe Rd., Cleveland, O.	PM	Canned motor—10–1,000					
Westinghouse Electric Corp., Atomic Equipment Dept., Cheswick, Pennsylvania	A11	Canned motor	2,500	7	7	11	60
	A30	Canned motor	7,310	11	11	23	280
	A150	Canned motor	17,500	33	33	16	925
	M900	Canned motor	~30,000	54	54	36	5,200
	D4000	Canned motor		78	30		6,950
	M8000	Canned motor		111	51	51	27,100
		Canned motor		30	15	15	600
		Tank type		72	42	42	6,000

Electromagnetic Pumps

Supplier	*Model*	*Cost ($)*	*Approximate dimensions*				*Rated capacity (gal/min)*
			Ht. (in.)	*Width (in.)*	*Length (in.)*	*Wt. (lb)*	
Allis-Chalmers Mfg.	EZ		26	8		175	40
	1A		30	30	60	800	3,800
Callery Chemical Co., Callery, Pennsylvania	0.5–150	2,500	16	18	15	125	1
	5–30	2,500	16	14	15	90	7
	25–30	3,000	20	18	23	280	50
General Electric Co.	Em		Dimensions vary				10–3,300
	915849	2,500	12	10	20	100	19
	EM		30	12	20	500	100

Rated capacity (gal/min)	Capacity variation (% of rated)	Max. design inlet pres. (psi)	Head (ft)	Min. net pos. suction head (ft)	Power required (volts)	Power required (amps)	Power required a-c phases	Efficiency at rated flow (%)	Max. temp. (°F)	What liquids can be pumped?	Pump materials	Remarks, special models
5–30	None	2,500	45–35	10	220/440	4.7/2.3	3	15	750	Any	ss	Fluid-piston bearings
4,000	None	2,500	300		440		3	65	500	Water, Na	ss	To 20,000 gal/min
6	None	2,000	100	10						Metals, Hg	ss	
400	5–100	50	126	2	230	73.7	d-c	60	1,200	Na, NaK	347 ss, pure Ni	
20	5–100		4		220	1.1	3		450	Clear	316ss, Monel	To 2,500 psi
40	5–100	300	90	4	220/440	3	3		450	Clear, light slurries	316ss, Monel, Carpenter 20	To 700° F, 5,000 psi
150	7–120	300	80	4	220/440	6	3		450	"	"	To 650° F, >300 psi
200	10–100	300	150	5	220/440	12	3		400	"	Iron, 316ss	To 650° F, >300 psi
40	5–100	300	140	5	220/440	4	3		450	"	"	To 700° F, 5,000 psi
20	0–100	300	22		115	4	1		400		316ss, Monel	Quantity production; 3-φ motors
15	0–100	100	20		110	18	1	35	1,000	NaK	347ss, Croloy	
100–20,000	Yes	3,000	50–750	5–100			3	<70	650	Water	ss	Same design all ratings
10	None	2,500	50	5	110/220	5.4/2.7	3	70	700	Any	ss	
30	None	2,500	115	5	220	20	3	70	700	Any	ss	
180–400	None	2,500	70–330	12–20	440	25	3	70	700	Any	ss	
5,300	None	1,725	120	45	440	220	3	70	700	Any	ss	
4,000	None	2,500	360	85	440	460	3	70	700	Any	ss	
15,000	None	2,500	360	90	2,300	405	3	70	700	Any	ss	
200	None	60	150		440	27	3	55	1,000	Na, NaK	ss	
4,500	None	100	14	12	440	195	3	70	1,200	Pb, Bi	Chrome-Moly	

Capacity variation (% of rated)	Max. design inlet pres. (psi)	Head (ft)	Min. net pos. suction head (ft)	Power required (volts)	Power required (amps)	Power required a-c phases	Efficiency at rated capacity (%)	Max. temp. (°F)	Pump materials	Remarks, special models
0–100	300	200	20	220/440	60	3	20	1,000	ss	Larger units available
0–100	200	160	60	120	20	d-c	35	1,200	ss	This is a centrifugal pump
0–250	300	280	0	230	15	1	25	1,500	316ss	To 1,500 gal/min and 150-psi head
0–200	300	80	0	230	10	1	25	1,500	316ss	
0–140	300	55	0	230	30	1	25	1,500	316ss	
0–100	100	0–150		10–440	30–1,000	3	to 45	1,000	Any, if compatible, ductile	Built and operated
0–150	100	19		250	30	1	3	1,600		Stocked catalog model
0–100	100			440		3	15	1,600		Actually d-c pump; rectifiers supplied

Pumps for Reactor Coolants (cont.)

Canned-motor pumps are shown undergoing final inspection before shipment to a large atomic-energy establishment in England. Since pumps require no lubrication they will be welded in place at site to provide complete hermetic sealing. Allis-Chalmers units shown deliver 15 gpm of liquid at 500° F against 35-ft head in 2,000-psig system

facturers listed are all prepared to build pumps to specifications and to provide special designs. Some of the manufacturers make similar leakless blowers for radioactive gases or gaseous reactor coolants. Write them for further details.

Other Suppliers

Some manufacturers of pumps for liquid nuclear-reactor coolants do not list specific models because their work is largely on special application. Included are:

Byron Jackson Co., P. O. Box 2017, Terminal Annex, Los Angeles 54, Calif. (Canned-rotor, canned-motor, gas-filled-motor, and other low-leakage mechanical pumps.)

Eastern Industries Inc., 100 Skiff St., Hamden 14, Conn. (Pumps for all reactor applications.)

General Electric Co., Medium Induction Motor Department, Schenectady, N. Y. (Electromagnetic a-c pumps of 3,300-gal/min capacity for liquid Na, NaK, and Li have been designed and are in actual operation.)

Ingersoll-Rand Co., Cameron Pump Sales Div., 11 Broadway, New York 4, N. Y. (Canned-rotor, gas-sealed centrifugal, and minimum-leakage pumps.)

Peerless Pump Division, Food Machinery and Chemical Co., 301 West Ave. 26, Los Angeles 31, Calif. (Pumps for specialized applications.)

Worthington Corporation, Nuclear Power Section, Marine Division, Harrison, N. J. (Canned-rotor, gas-sealed centrifugal, and controlled-leakage pumps in capacities above 2,000 gal/min and horsepowers above 100 hp for water and capacities above 500 gal/min in the case of liquid metals.)

• • •

Copies of this survey, at 10 cents each, can be obtained from Reprint Department, NUCLEONICS, 330 West 42nd St., New York 36, N. Y.

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2. W. B. Cottrell, L. A. Mann, NUCLEONICS **12**, No. 12, 22 (1954)
3. D. P. Litzenberg, H. T. White, *Chem. Eng. Progr.* **50**, No. 9, 437 (1954)
4. A. H. Barnes, F. A. Smith, G. K. Witham. Electromagnetic pump for liquid metals, AECD-3431 (1949)

RADIATION DETECTORS AND ACCESSORIES

100-Channel Pulse-Height Analyzers

Commercial versions of two multichannel analyzers recently developed are available (NU, April '55, p. 76).

• The PA-3 analyzer, based on Los Alamos design, has 100 channels with 0–99,999-count capacity. Channel width is either 0.5 or 1.0 volts uniform to 0.2%. Memory is by magnetic cores. Three methods of data presentation are possible: (a) linear spectrum plot on scope, (b) a neon-lamp readout of each channel in turn, and (c) printed tape with provision for total or subtotal printouts after each 1, 2, 5, 10, or 100 channels. Many other features.—Pacific Electro-Nuclear Co., 8930 Linblade St., Culver City, Calif.

• A British version of the Hutchinson-Scarrott analyzer makes up to 120 channels available. In 80-channel operation it can record 3×10^4 pulses per channel. Pre- and main amplifier are provided. Memory is mercury delay line. Data presentation is by array of brightened dots on scope face.—Sunvic Controls Ltd., 10 Essex St., Strand, London, W. C. 2.

X-Ray Ion Chambers

Accurate to 5% for 6–35-kev energies, the Model 651 250-r chamber can be used at intensities to 100 r/sec. Model 612 probe measures 10–9,990 r to 10% when used with Radocon integrating ratemeter. Both chambers have Kodapak windows.—Victoreen Instrument Co., 3800 Perkins Ave., Cleveland 14, Ohio.

Correction to Shielding Materials Report

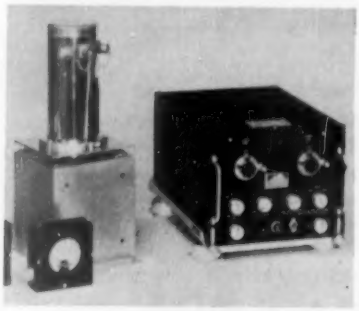
The tenth-value layer thicknesses given for high-density concrete, as part of the Portable Radiation-Shielding Materials report in the May, 1955 issue, are in error. The correct values are: $t_{1/10}$ = 4.8–3.3 in. for 1.25-Mev γ, 3.5–2.5 for 0.66, 2.6–1.8 for 0.35. The first thickness for each energy is for a concrete with specific gravity of 3.4, the second figure is for a concrete with 4.8 specific gravity. See p. 24, this issue, for a discussion of the meaning of tenth-value layer thickness.

Transistorized G-M Counter

Model 411 has 0–0.02, 0.2, 2.0-mr/hr ranges, weighs less than 4 lb., and has built-in audio amplifier (also available separately). Other models available.—Universal Atomics Corp., 19 E. 48th St., New York, N. Y.

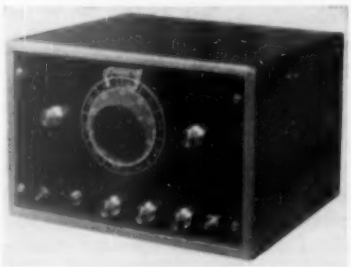
Balanced Ion Chamber

Model BIC-2 weighs 18 oz., uses hearing-aid batteries. Balancing radiation is provided by radium-treated meter needle that provides increasing balancing radiation as incident radiation increases. Scale reads 0.05–50-mr/hr.—Librascope Inc., 808 Western Ave., Glendale, Calif.



5-in. Scintillation Counters

SC-188DA airborne-carborne scintillation counter system (above) has two discriminators for single-channel analysis of pulses from 3- or 5-in. NaI crystal and photomultipler. Dual recorders are used for altitude and counting rate. Also available is SC128A airborne system and SC129 portable counter with 1½-in. crystal. —Mt. Sopris Instrument Corp., 1320 Pearl St., Boulder, Colorado.



Mercury Pulse Generator

Model M-60 puts out 10-μvolt–100-volt pulses. Rise time is better than 5×10^{-8} sec. Decay time is 1, 10 or 100 μsec.—Radiation Instrument Development Laboratory, 2337 W. 67th St., Chicago 36, Ill.

Plug-In Scale-of-10

Employing miniature tubes and the direct-reading EIT decade-scaler tube, new octal plug-in weighs only 8 oz. Models are available for 20, 40, and 100-kc operation and for feeding mechanical registers.—Ransom Research, P. O. Box 382, San Pedro, Calif.

•

Drill-hole logger. Scintilogger has minimum of 2,000 ft. of cable with 900-lb rating. Time constants are 1, 4, and 16 sec; sensitivity is 600, 1,800 and 6,000 cpm.—The Radiac Co., 489 Fifth Ave., New York 17, N. Y.

Scanner. Mediscanner for plotting distribution of body radioactivity has automatic scanning sequences and motor-driven vertical motion. Detector is tungsten shielded. Guide light shows sensitive spot below detector. Printing is with electrically sensitive paper.—NRD Instrument Co., 6425 Etzel Ave., St. Louis 14, Mo.

Probe. Probitron, Model FAX16X, has sensitive scales from 0.1 to 10,000 r/min for X-ray therapy. For diagnosis FAX161 can detect iodine uptake from oral doses as low as 5 μc. Other probes are available.—R-C Scientific Instrument Co., Inc., 307 Culver Blvd., Playa del Rey, Calif.

Aerial survey meter. DS-7 system has 3-in. NaI crystal, ratemeter, recorder and alarm. Weighs less than 75 lb. Sensitivity is 3,000,000 cpm per mr/hr.—Nuclear Instrument & Chemical Corp., 229 W. Erie St., Chicago 10, Ill.

Distributed amplifier. Besides 200-kc–250-mc bandwidth, model 500 has 12-db power gain between 90-ohm input and 160-ohm, 3-w, 22-volt (rms) output.—Instruments for Industry, Inc., 153 Glen Cove Rd., Mineola, N. Y.

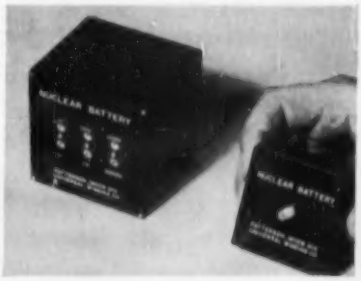
Long G-M tube. Halogen-filled type 912NB is 12 in. long, has 7-in., stainless-steel, 30-mg/cm² cathode. Minimum plateau is 200 volts; operating voltage is 900 volts.—Amperex Electronic Corp., 230 Duffy Ave., Hicksville, N. Y.

Pulse generator. Model 3420A has 90-cycle–3.3-megacycle repetition rate; 0.1-μsec wide pulses are variable to 25 volts.—Electro-Pulse, Inc., 11811 Major St., Culver City, Calif.

Marker generator. B4-100 marker generator provides 0.1 and 1-μsec + or − marker signals with 0.01% accuracy. Used with B4-200 oscillator it can measure rise times from a few mμsec to tens of μsec.—Rutherford Electronics Co., 3707 S. Robertson Blvd., Culver City, Calif.

Cadmium sulfide cell. CdS photoconductive cells, type 6694, which have found application in X-ray intensity measurements are available in head-on miniature style with lineotetrar base.—Tube Division, Radio Corp. of America, Harrison, N. J.

RADIOACTIVITY MATERIALS AND APPARATUS



Nuclear Batteries

Using Sr^{90} as the energy source results in operating life of over 25 yr for three models of nuclear batteries. Multiple-voltage source has taps at 1, 10, 100, and 1,000 v and a current of

Products Index

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2 μa. Another battery supplies 375 v at 50 μμa. High-voltage source supplies 500 μμa at 10^4 v.—Patterson-Moos Division, Universal Winding Co., Box 1605, Providence, R. I.

Wall-Thickness Gage

Using a Ra source in two types of heads, the Penetron measures wall thicknesses to within 3%. Tangential head is designed for tubular goods, standard head is for plates. Access is needed from only one side for both heads.—United Engineers Inc., 820–824 E. 6th St., Tulsa, Okla.

Shielding Materials

Here are two unusual materials for use in shielding. A line of metal-impregnated plastics and a non-hardening compound that contains lead are available.

• K-Rashield compounds are plastics that contain materials for γ-ray and neutron shielding. Most formulations can be welded or machined. Productions pieces weighing ounces or tons are possible. Following are weight % of additive materials in typical combinations: lead–80, 90, and 92%; boron carbide–24, 41, and 74%; also 88% lead–4.5% boron carbide; cadmium–50, 70, and 90%; also 86% lead–6.9% cadmium; tungsten–70, 82, and 95%; also 69% lead–26% tungsten.—K-plastic, 55 Elmira St., San Francisco 24, Calif.

• Plastic Lead Seal pipe compound contains about 80% lead, never hardens. Compound is unaffected by steam or chemicals. Various consistencies are sold.—Crane Packing Co., 1800 Cuyler Ave., Chicago 13, Ill.

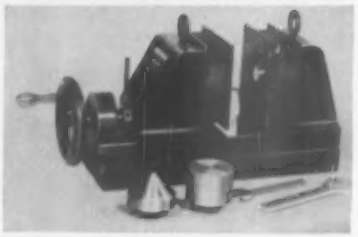
Paper Products

Waterproof disposable paper aprons head a list of items that find use in radiochemical labs. Others are absorbent paper for drippings, black waterproof paper, plastic microscope coverslips, can liners, and face masks.—Robert Busse & Co., Inc., 64 E. 8 St., New York 3, N. Y.

Civil-defense calculators. Two circular slide-rule calculators for use after atomic explosions give dosage and contamination data. Three scales give dose rate and total dosage data knowing only dose rate at one time after explosion using Radiac Calculator No. 1. Water contamination calculator gives water activity as related to tolerance level.—Blundell Rules Ltd., Chaul End Lane, Lutton, England.

Fume and dust arresters. Water washer unit removes contaminants and dust from air streams. It is rubber lined for protection against corrosive fumes. Various sizes are available. Package dust collector has a built-in reservoir that permits recycling of water to reduce consumption. Attached adjustable hood provides dust entrapment.—Schmieg Industries, Inc., Box 4701, Detroit, Mich.

LABORATORY INSTRUMENTS AND APPARATUS



30,000-Gauss Electromagnet

Normal operating current is 10 amp at 75 volt d-c for this efficient electromagnet. Several pole faces are available and gap is variable; fields range from 13,000 gauss for 9-cm-diameter pole face and 1-cm gap to 32,200 gauss for 1-cm-diameter face and 0.25-cm gap.—Sunshine Scientific Instrument, 1810 Grant Ave., Philadelphia 15, Pa.

Economical Dust Mask

GS No. 48A masks protect against nontoxic dusts. Weight is ½ oz., material is soft rolled aluminum, pliable enough to fit face. Filter material is bonded long-staple cotton.—General Scientific Equipment Co., 2700 W. Huntingdon St., Philadelphia 32, Pa.

Dual Pyrometer

Controlling two temperatures independently and simultaneously, the model 355 dual pyrometer also monitors two additional temperatures. Iron-Constantan thermocouples are the pick-ups used. Control action on each of a pair of couples at two locations is possible. Temperature ranges from −400 to 3,000° F are available on different models. Load relay is 5 amp, 150 v a-c, relays to 20 amp can be supplied.—Assembly Products Inc., Chesterland, Ohio.

Constant-Pressure Pump

Movable end plate automatically adjusts to maintain constant output with varying input pressure in Hydro Variable Cavity pump. Output pressure can be from 3–75 psi. Pump has reversible rotation.—Hydro Engineering Inc., 700 39th Ave., N. E., Minneapolis 21, Minn.

Rapid Analysis Tools

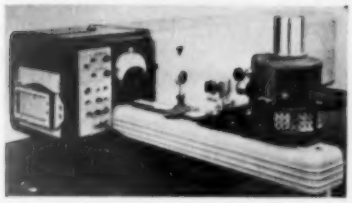
An X-ray scanning spectrometer, an X-ray absorption gas analyser, and two new recording spectrometers are available for rapid analysis work, either research or production control.

• All forms of samples can be analyzed with little preparation using the X-ray scanning spectrometer (above) just announced. Accuracy comparable to the best chemical methods, with procedural simplicity and speeds similar to direct-reading optical emission methods are claimed.—Applied Research Laboratories, Glendale, Calif.

• Using X-ray absorption, a new gas analyzer detects high-atomic-weight elements quantitatively. The analyzer has a monochromatic beam for more accurate results. An absorption standard is provided.—North American Philips Co., 750 S. Fulton St., Mount Vernon, N. Y.

• With 1-min interchange of its four prisms, the model 4-55 infrared recording spectrophotometer has a spectral range of 1.5–26 microns. The recording system has scanning-speed, slit-width and amplifier-gain controls, for switching between qualitative and quantitative programs. The device can be operated round-the-clock.—Baird Associates, Inc., 33 University Rd., Cambridge 38, Mass.

• Model 14 recording spectrophotometer has good performance to 1,900 Å or shorter wavelengths. Analytical procedures with this standard model for aromatics, ketones, alcohols and other compounds are thus open.—Applied Physics Corp., 362 W. Colorado St., Pasadena, Calif.



Versatile Spectrograph

Using one grating with a range of 1850–2400 Å and one with range of 1850–1200 Å, a new dual grating spectrometer (above) will photograph complex spectra. Both ranges may be photographed on a single plate or two plates may be used. Faster analyses are claimed. Instrument has a step variable slit.—Bausch and Lomb Optical Co., 635 St. Paul St., Rochester 2, N. Y.

Dual Titrometer

Allowing two titrations to be run simultaneously, the Dual Titrometer (above) responds to electrode current of 10^{-13} a. Full *p*H range is measurable to 0.02 *p*H unit. Readings are made from continuous-reading meter dial.—Precision Scientific Co., 3737 W. Cortland St., Chicago 47, Ill.

Measurement Devices

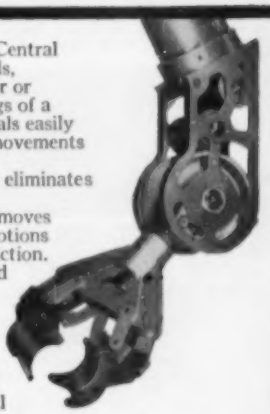
Three linear-measurement instruments; a dial-reading rule, a ruled-eyepiece pocket microscope, and a precision comparator are being sold.

• With direct dial-reading of 0.001 in. the Dial-Cal has a rack and pinion arrangement that transfers readings to dial face. Range of 6-in. is provided. Built of stainless steel, unit can measure outside and inside dimensions, depth, narrow recesses.—Precision Tool Sales, 417 E. Florence Ave., Los Angeles, 3, Calif.

• Pen-sized Indeco 50-power microscope has 0.1 in. on reticle divided into scale markings of 0.001 in., allowing on-the-spot estimates to 0.0005-in. Focusing is done by tilt-

master-slave manipulators

handle dangerous materials with a gentle touch



Master-Slave Manipulators manufactured by Central Research Laboratories handle radioactive materials, explosives and dangerous chemicals. Reaching over or through protective barriers, the manipulating tongs of a Master-Slave unit lift, twist, turn and mix materials easily and accurately. Slave tongs smoothly reproduce movements of thumbs and forefingers of the operator's hands. The unusual "sense of feel" of the controls almost eliminates the need for operator training.

Only 2 ounces of force overcomes friction and moves arms in any horizontal direction. Up and down motions require forces as small as 5 ounces to overcome friction. Master handles are easily adjustable to fit all hand sizes. If operations are repetitive, special tongs can be supplied to increase speed and ease of handling. Special slave ends can be supplied to increase the mechanical advantage of the grasping or holding action.

Developed from basic designs of the Remote Control Engineering Division at Argonne National Laboratory, all components are precision made from finest materials for dependable performance.

For complete information, write to

Dept. 201—Red Wing, Minnesota

Central Research **laboratories, inc.**

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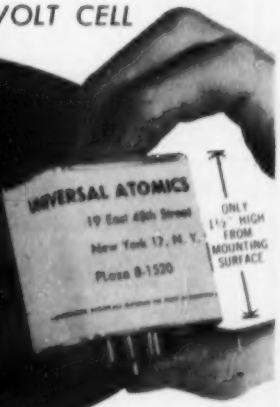

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Airborne scintillation system. Booklet describes DS-7 counting system for aerial surveying. 8 p.—Nuclear Instrument and Chemical Corp., 229 W. Erie St., Chicago 10, Ill.

Reactor components. Electromagnetic pumps for coolants, control instrumentation, remote manipulators, and reactor engineering are listed in bulletin GEA-6014. 4 p.—General Electric Apparatus Sales Div., Schenectady 5, N. Y.

Timers. Catalog lists 37 clocks, counters, and printing timers. 8 p.—C. H. Stoelting Co., 424 N. Homan Ave., Chicago 24, Ill.

Prospecting instruments. Catalog lists G-M and scintillation counters, metal detectors, and u-v sources for prospectors. 12 p.—Fisher Research Laboratory, Inc., 1961 University Ave., Palo Alto, Calif.

Strippable coating. News bulletin describes properties of G. E. Cocoon, a 0.75-gm/cm² resistant strippable coating.—R. M. Hollingshead Corp., 840 Cooper St., Camden, N. J.

Automation cylinders. Catalog 55 gives specifications for line of air- and hydraulic-operated cylinders. 8 p.—Hydro-Line Mfg. Co., 5737 Pike Rd., Rockford, Ill.

Water filters. Release 214 describes stainless-steel filters for 8–939-gpm systems.—Micro Metallic Corp., 30 Sea Cliff Ave., Glen Cove, N. Y.

Amphenol connectors. Catalog B4 gives complete listing of connectors. Request on company letterhead.—American Phenolic Corp., 1830 S. 54 Ave., Chicago 50, Ill.

Spectrograph source unit. Bulletin 35A describes unit for high-voltage condensed spark, a-c arc, and d-c arc source operation. 4 p.—Baird Associates, Inc., 33 University Rd., Cambridge 38, Mass.

Flow interlocks. Folder 260 describes Shurflo interlocks for protecting equipment when liquid flow is below minimum or above maximum. 12 p.—Industrial Sales Div., Dept. 437, Hays Mfg. Co., W. 12 St., Erie Pa.

Surface-tension tester. Bulletin 2 illustrates how Jiffy Loop tests surface-tension quickly.—Pollack Products, 1628 E. 7 St., Brooklyn, N. Y.

Silicon junction diodes. Bulletin gives information on manufacture and properties of diodes. 8 p.—Hughes Aircraft Co., Culver City, Calif.

Heat detectors. Thermistor cells that measure heat at a distance are described in 4-page brochure.—Servo Corporation of America, New Hyde Park, N. Y.

Cenco catalog. "Labaratus" is title of 350-item scientific-apparatus catalog and complete price list. 64 p.—Central Scientific Co., Chicago, Ill.

Casting process. Brochure describes new combination of plaster-mold and investment casting processes. 4 p.—

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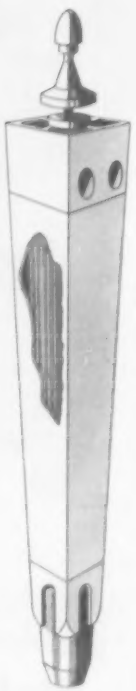

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Control instruments. Composite catalog 5002 lists industrial instruments for indicating, controlling, and recording many variables. 24 p.—Minneapolis-Honeywell Regulator Co., Wayne and Windrim Aves., Philadelphia 44, Pa.

Power supplies. Catalog 55 describes series of industrial and laboratory power supplies. 24 p.—Lambda Electronics Corp., 103-02 Northern Blvd., Corona 68, N. Y.

Indicating recorders and controllers. Information about new series of indicators, recorders and controllers is given in data sheets ND46-33(100-104). 28 p.—Leeds and Northrup Co., 4934 Stenton Ave., Philadelphia 44, Pa.

Silicon and germanium products. Data sheets on power rectifiers, diodes, and junction and power transistors are offered in bulletins TE-1300, 1308, 1319-1322.—Transistron Electronic Corp., 407 Main St., Melrose, Mass.

Pump-turbine report. Reprint 02R8245 explains design of pump-turbines and generator-motor units to smooth load curves. 12 p.—Allis-Chalmers Mfg. Co., 1316 S. 70th St., Milwaukee, Wis.

Precision-bore glass. Catalog 80-20 describes stock items in precision-bore quartz, Vycor and other types of glass. 4 p.—Fischer and Porter Co., 379 Jacksonville Rd., Hatboro, Pa.

Mercury-vapor detection. Folder describes line of Hg-vapor detection meters. Bibliography on Hg hazard is included. 4 p.—Harold Kruger Instruments, P. O. Box 164, San Gabriel, Calif.

Pneumatic flow meters. Bulletin 285-G2A contains data on line of pneumatic flow meters for fluids. 4 p.—Builders-Providence Inc., 345 Harris Ave., Providence, R. I.

Consulting laboratory. Information brochure on scientific research and development services is available. 28 p.—Truesdail Laboratories, Inc., 4101-4107 N. Figueroa St., Los Angeles 65, Calif.

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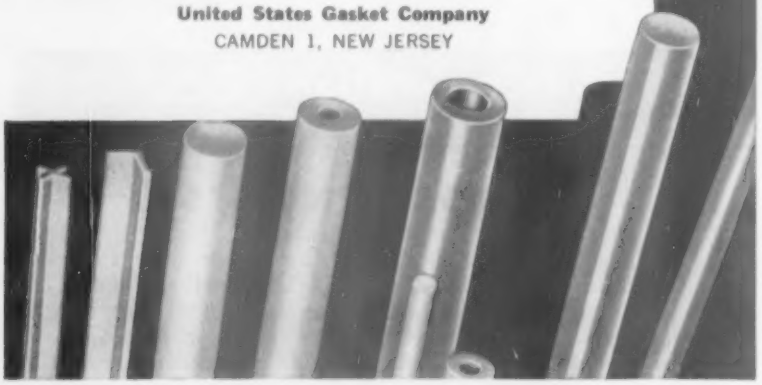

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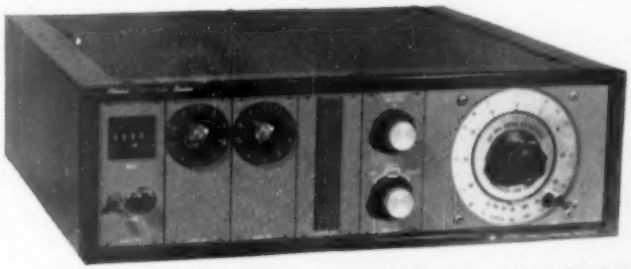

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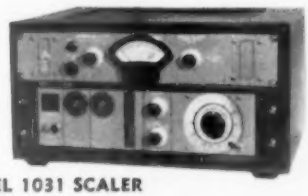

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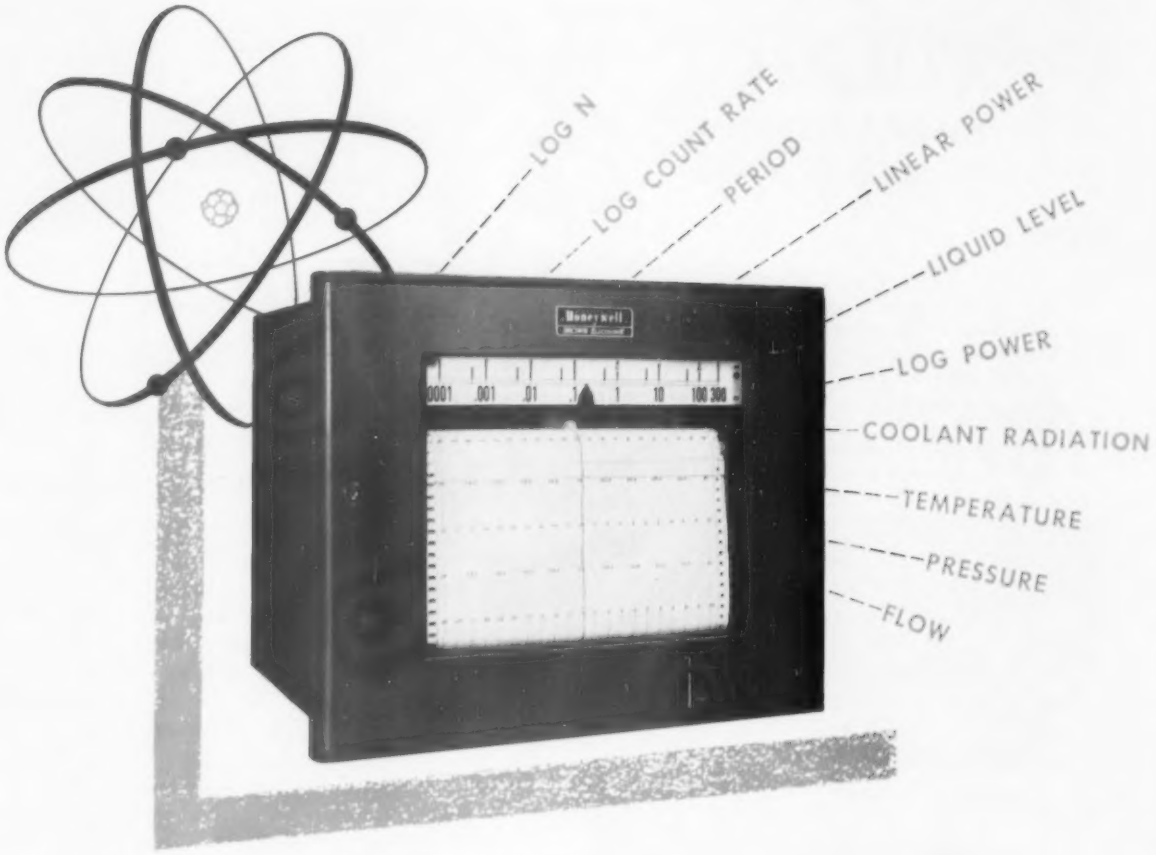

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